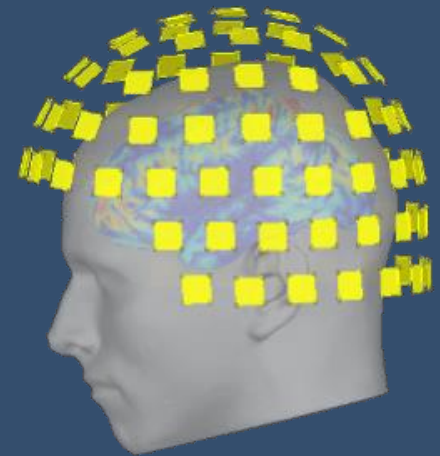


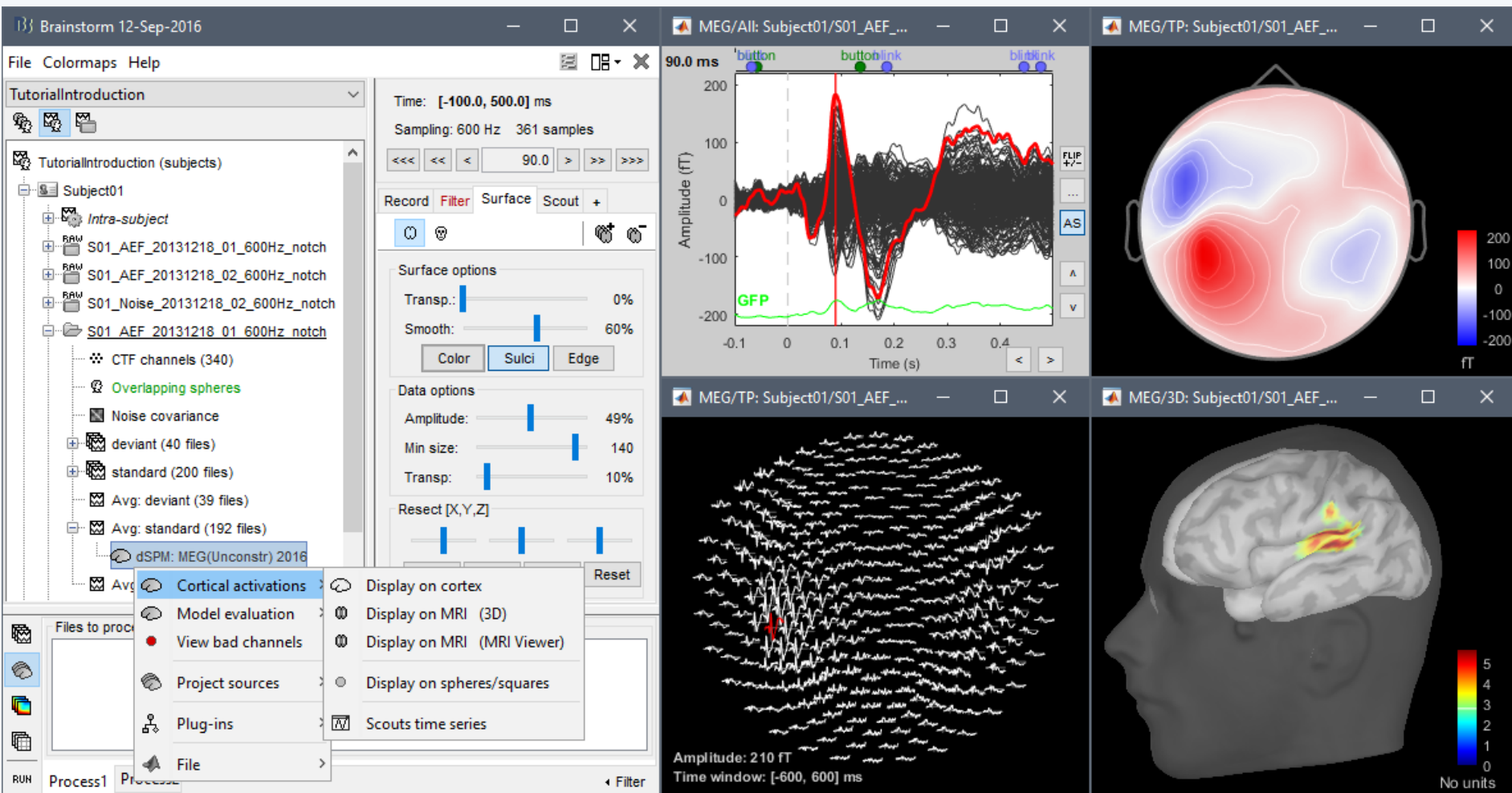
MEG and EEG analysis using  
**Brainstorm**  
<http://neuroimage.usc.edu/brainstorm>



**PracticalMEEG 2019**  
**Francois Tadel**



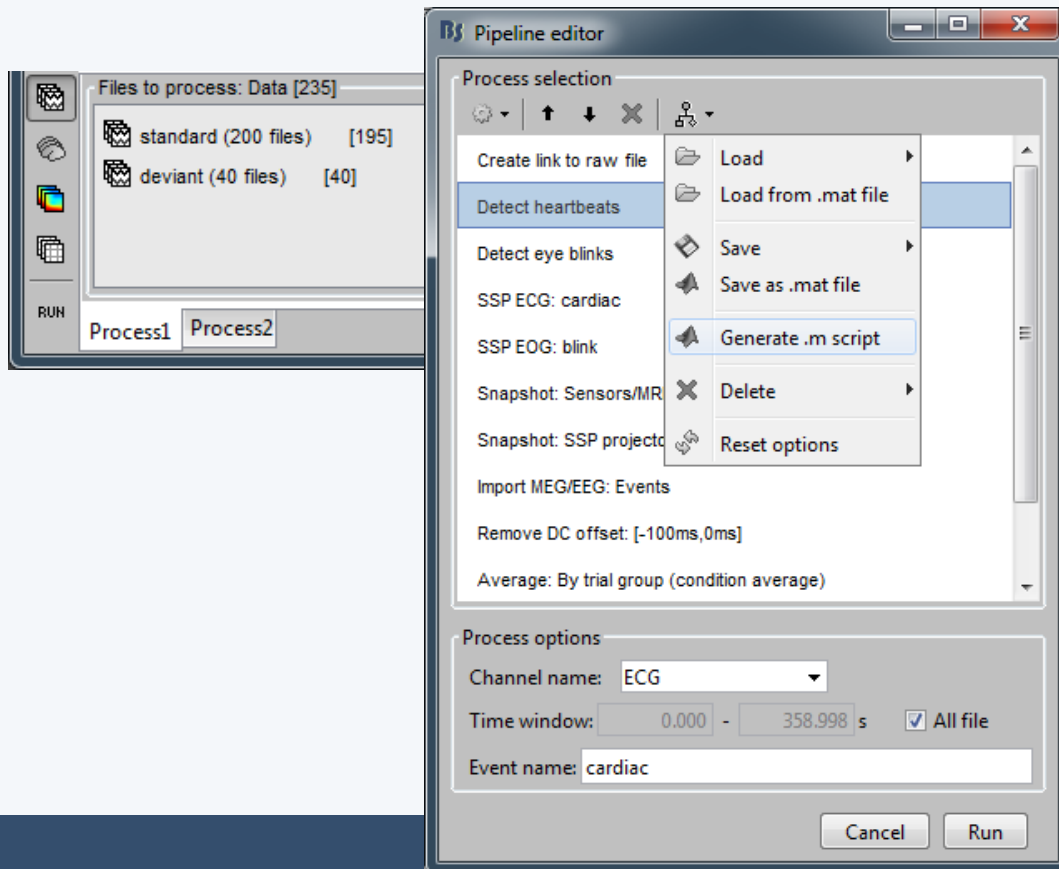
# Graphic interface





# Scripting environment

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



```
1 % Script generated by Brainstorm v3.1 (17-Dec-2010).
2 FileNamesA = {'Subject01\Left\data_average_101213_1558.mat', ...
3               'Subject01\Right\data_average_101213_1559.mat'};
4 FileNamesB = [];
5
6 % Process: Detect bad trials: Peak-to-peak MEGGRAD(0-2000)
7 sFiles = bst_process(...
8     'CallProcess', 'process_detectbad', ...
9     FileNamesA, FileNamesB, ...
10    'timewindow', [-0.0998, 0.3000], ...
11    'meggrad', {[0, 2000], 'fT/cm (x 0.04)', 1e-015}, ...
12    'rejectmode', 2);
13
14 % Process: Remove baseline: [-100ms,-1ms]
15 sFiles = bst_process(...
16     'CallProcess', 'process_baseline', ...
17     sFiles, [], ...
18     'baseline', [-0.09983, -0.00056], ...
19     'overwrite', 1);
20
21 % Process: Band-pass filter: 1Hz - 80Hz
22 sFiles = bst_process(...
23     'CallProcess', 'process_bandpass', ...
24     sFiles, [], ...
25     'f1', 1, ...
26     'f2', 80, ...
27     'overwrite', 1);
28
29 % Process: Average by condition
30 sFiles = bst_process(...
31     'CallProcess', 'process_average', ...
32     sFiles, [], ...
33     'avgttype', 3, ...
34     'isstd', 0);
```



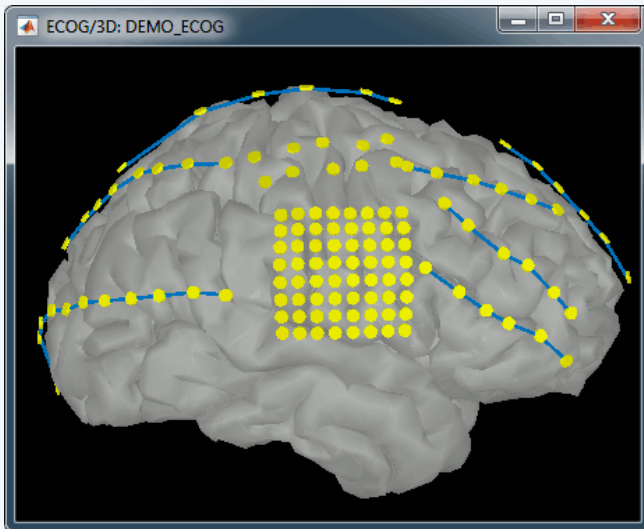
- Free and open-source application
- Matlab & Java: Platform-independent
- Designed for Matlab
- Stand-alone version available
- Interface-based: click, drag, drop
- No programming experience required
- Daily updates of the software
- Supports most common file formats



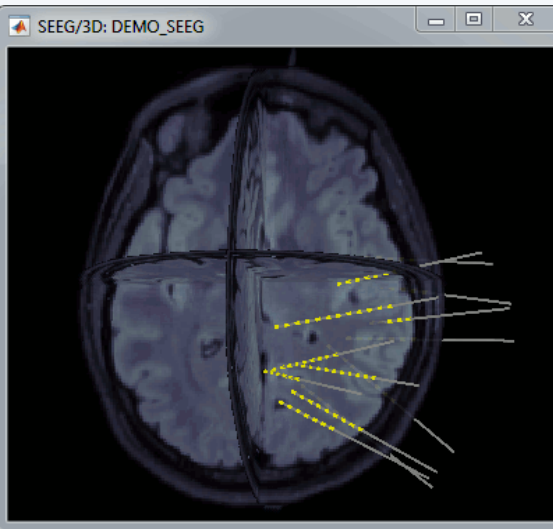


# Multi-modal imaging

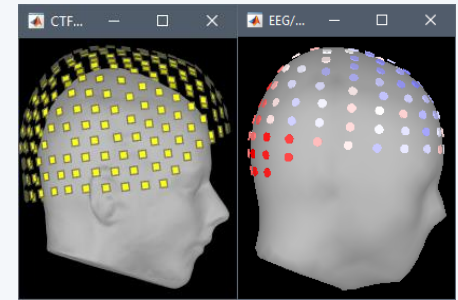
ECoG



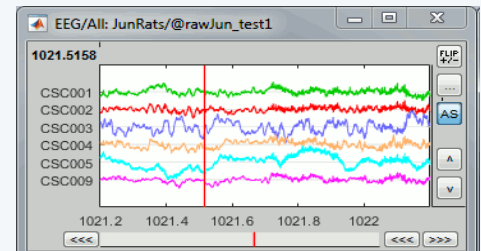
Depth electrodes



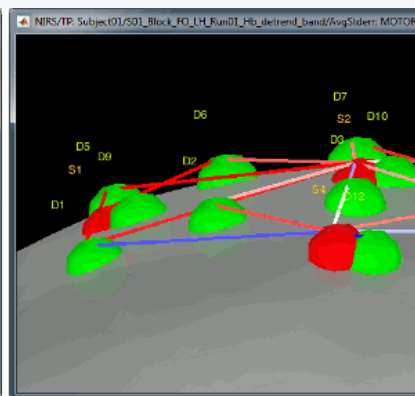
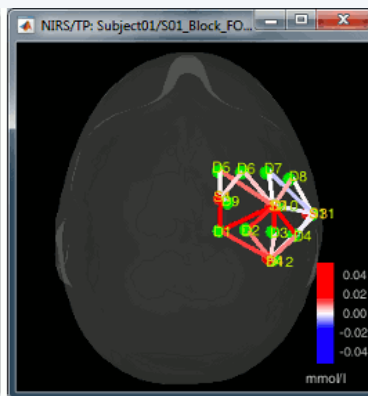
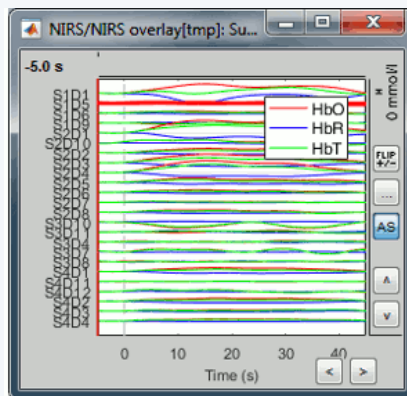
MEG/EEG



Electrophysiology



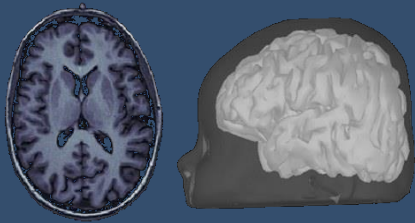
fNIRS



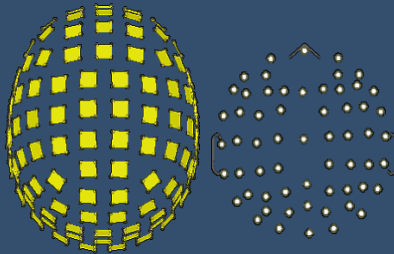


# Workflow

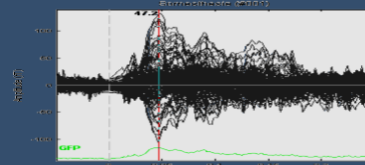
## Anatomy



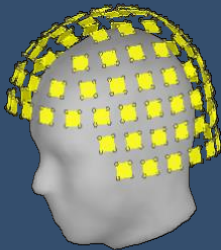
## Sensors



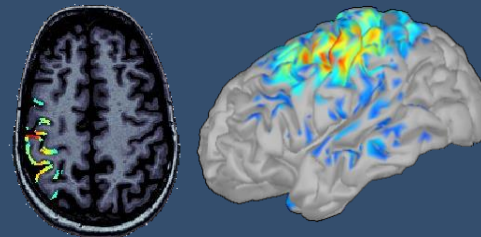
## EEG/MEG



## Co-registration



## Source estimation



## Analysis

Averages  
Contrasts  
Group analysis  
Time-frequency  
Connectivity



## Anatomy

Link recordings  
MRI registration

PSD

Filters

Bad channels

Artifacts

Correction

Bad segments

Markers

Epoching

Averaging

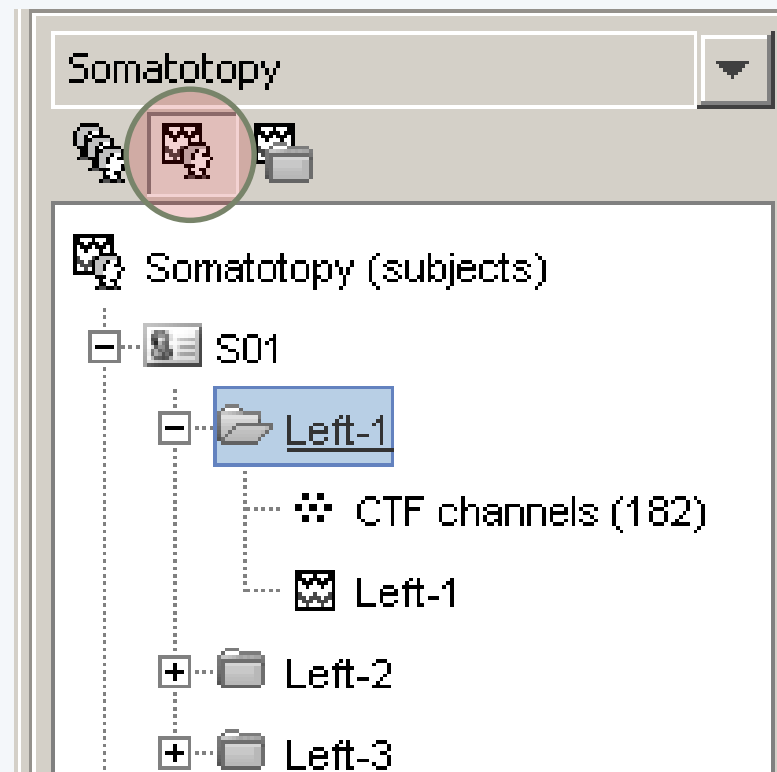
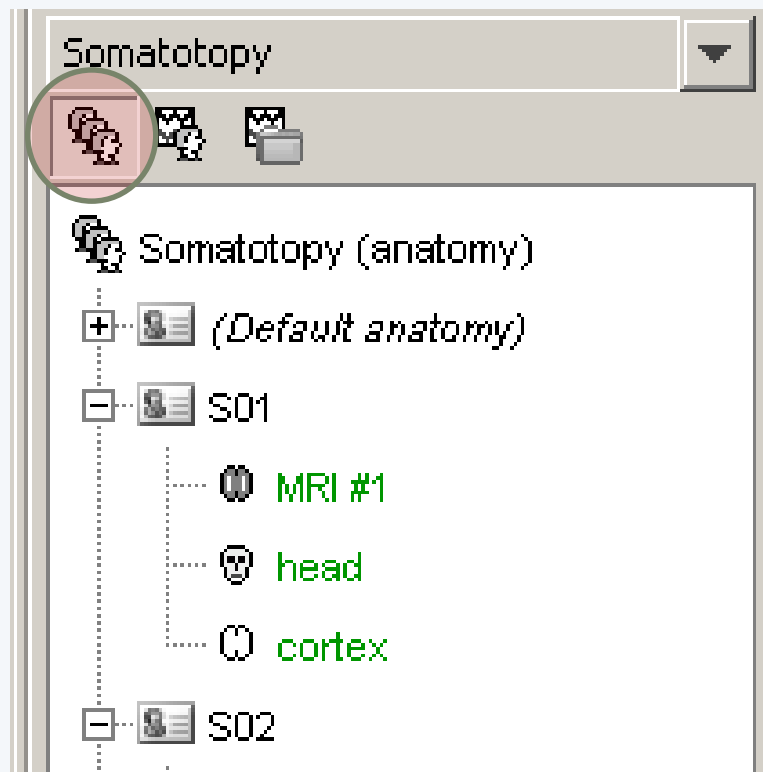
Sources

Time-frequency

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







- 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

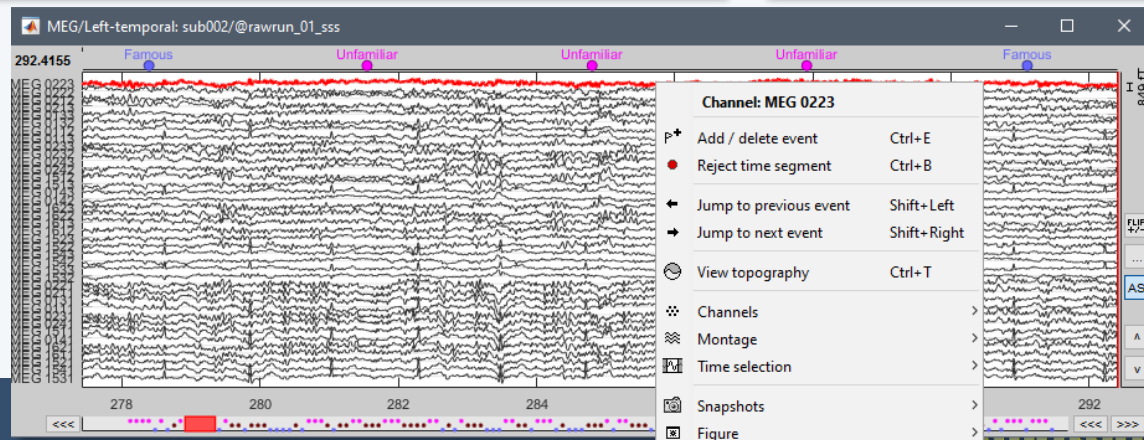
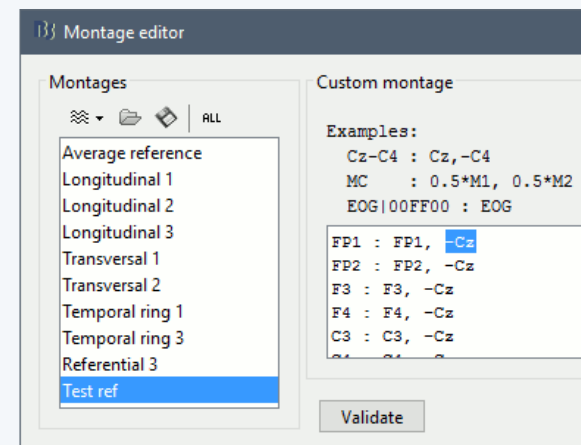
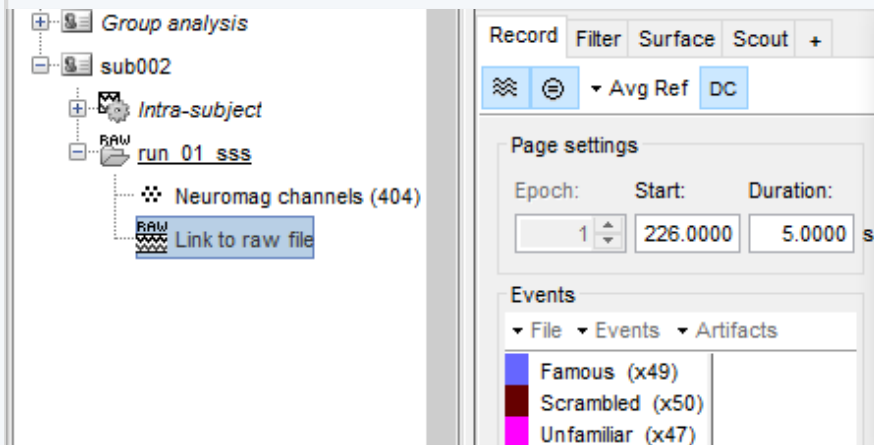
Epoching

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 (2)

Anatomy

Link recordings

**MRI registration**

PSD

Filters

Bad channels

Artifacts

Correction

Bad segments

Markers

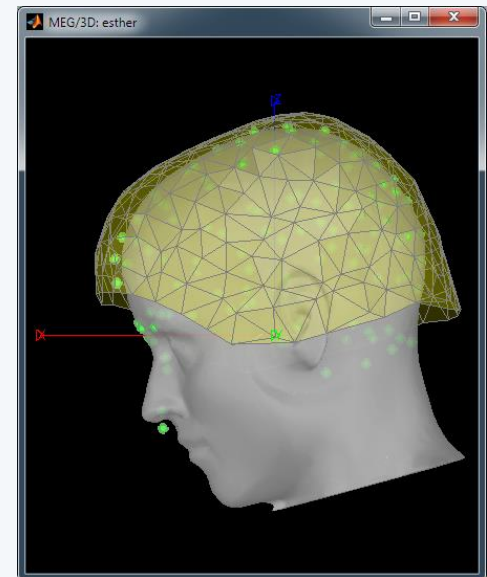
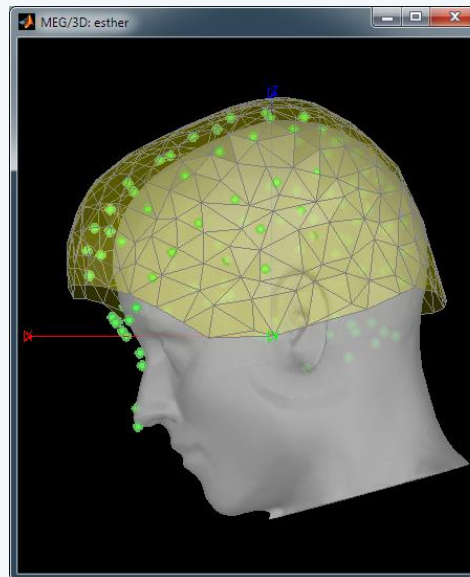
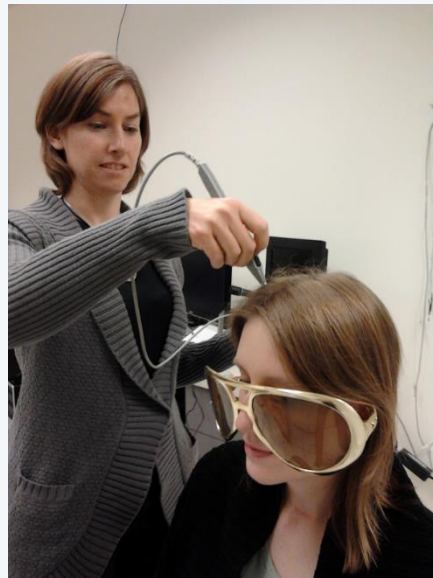
Epoching

Averaging

Sources

Time-frequency

- 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

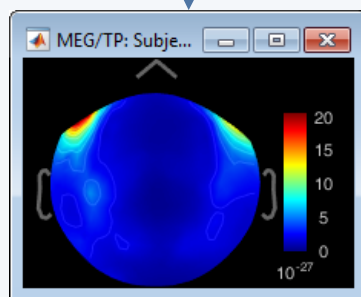
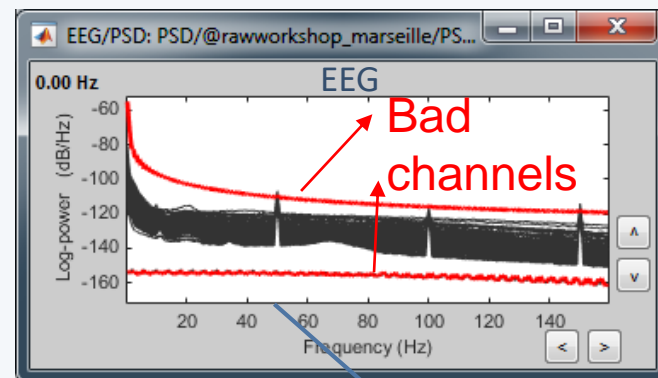
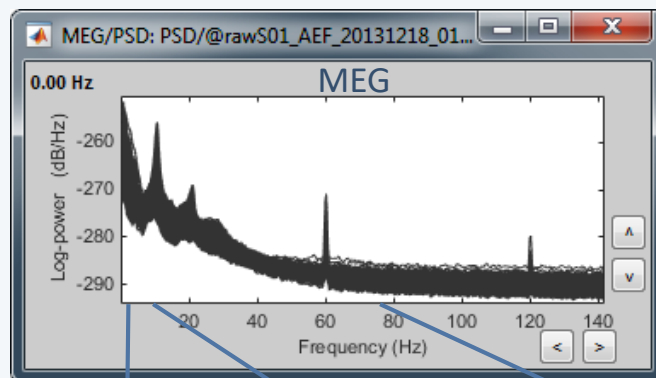
Anatomy  
Link recordings  
MRI registration

## PSD

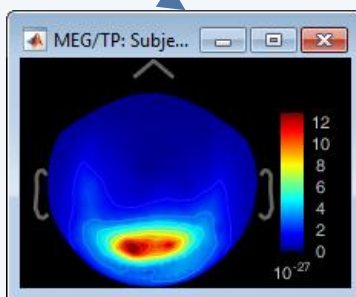
Filters  
Bad channels  
Artifacts  
Correction  
Bad segments

Markers  
Epoching  
Averaging  
Sources  
Time-frequency

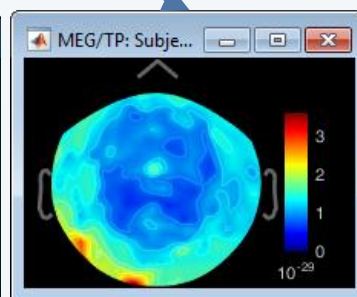
- Power spectrum density for quality control



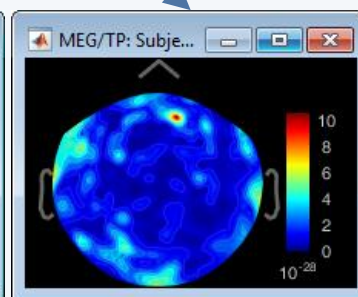
< 3Hz: Eyes



10Hz: Alpha



> 40Hz: Muscle



50/60Hz



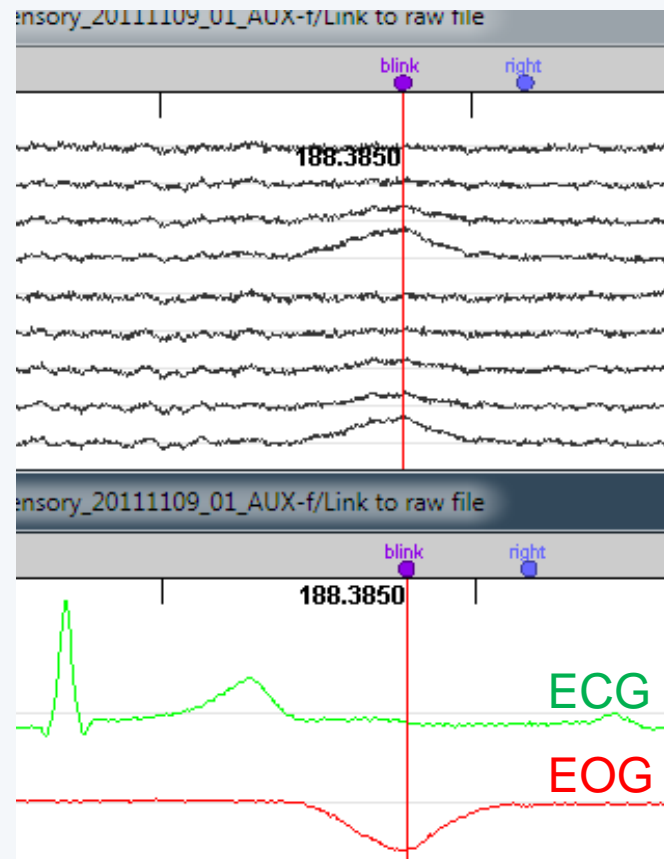
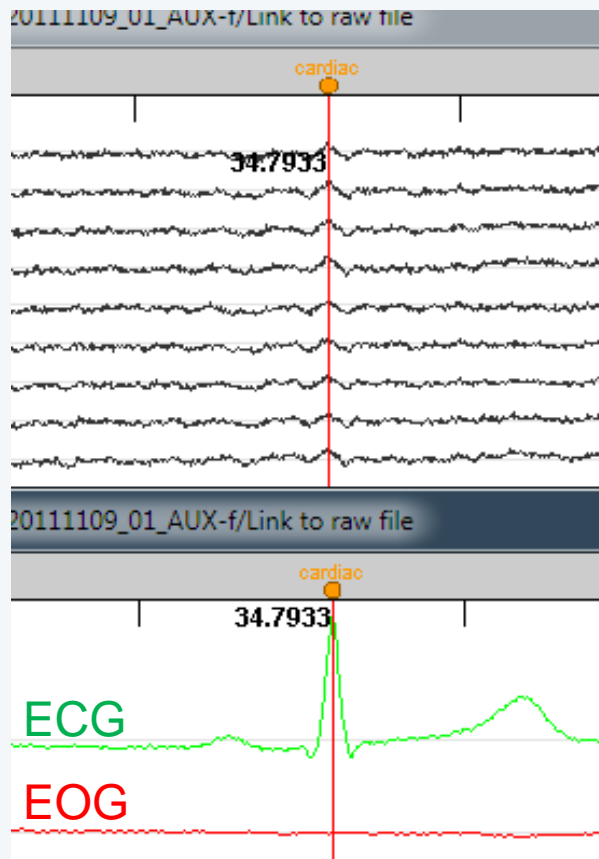
# Pre-processing

Anatomy  
Link recordings  
MRI registration

PSD  
Filters  
Bad channels  
**Artifacts**  
Correction  
Bad segments

Markers  
Epoching  
Averaging  
Sources  
Time-frequency

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





# Pre-processing

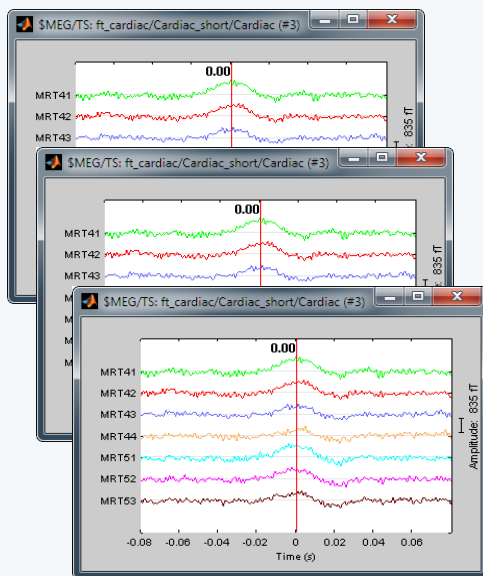
Anatomy  
Link recordings  
MRI registration

PSD  
Filters  
Bad channels  
Artifacts  
**Correction**  
Bad segments

Markers  
Epoching  
Averaging  
Sources  
Time-frequency

- Correction with Signal Space Projections (SSP)

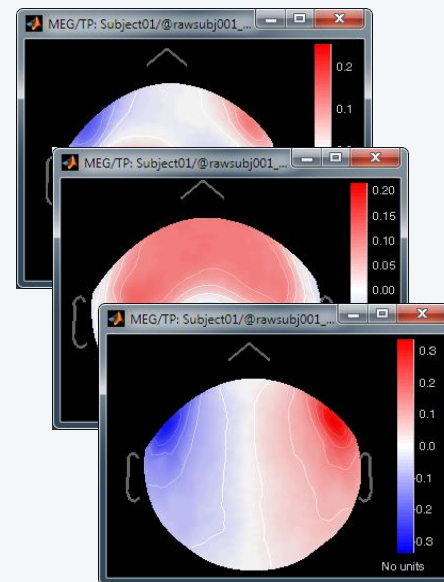
Detect artifacts



PCA



Spatial components

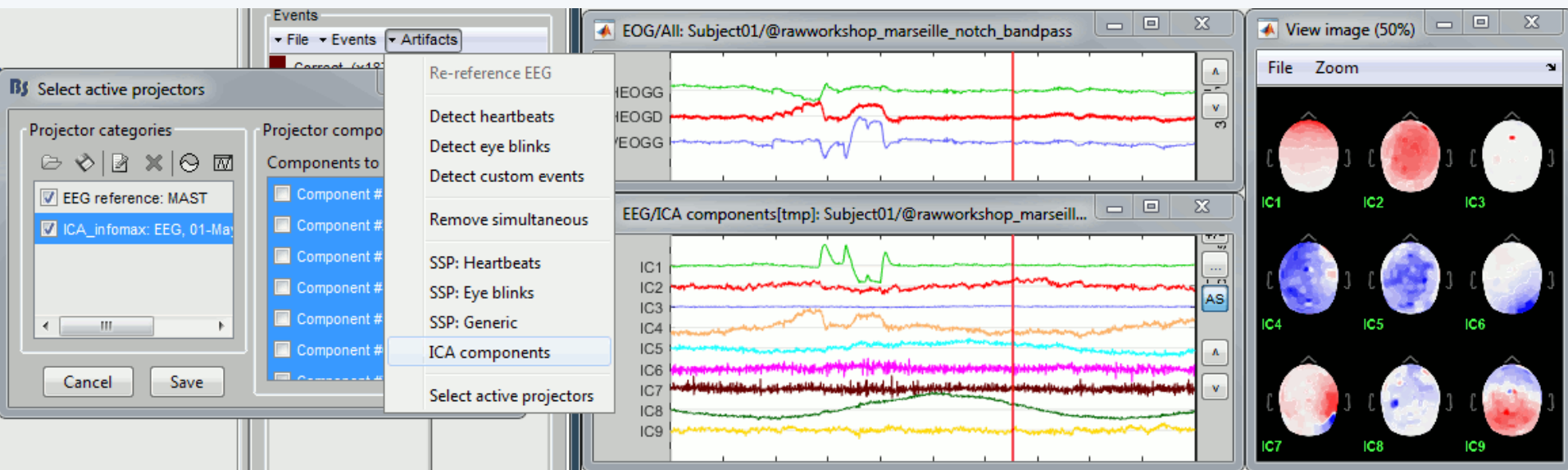


Select components and compute a linear projector to remove their contribution from the recordings



# 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)





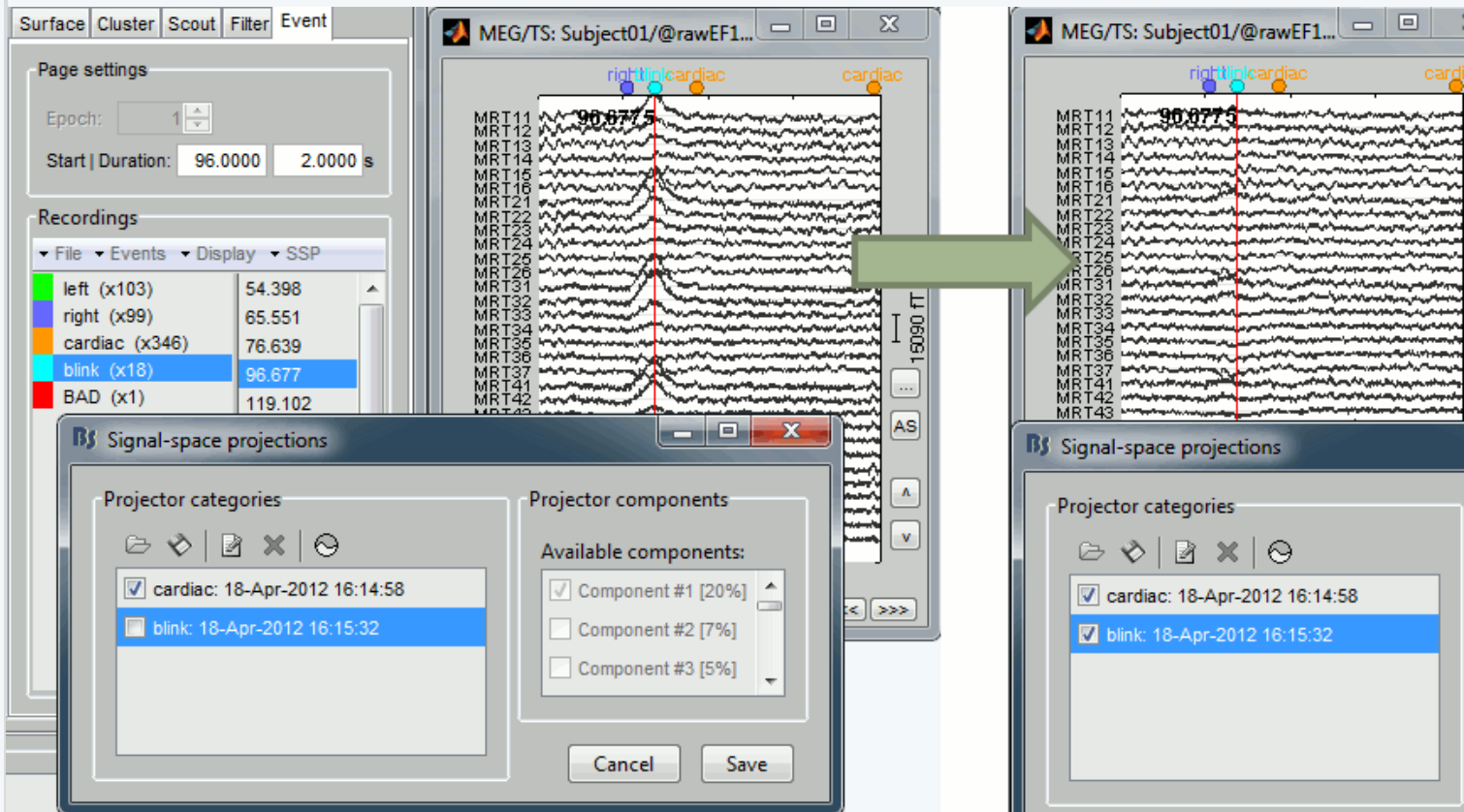
# Pre-processing

Anatomy  
Link recordings  
MRI registration

PSD  
Filters  
Bad channels  
Artifacts  
**Correction**  
Bad segments

Markers  
Epoching  
Averaging  
Sources  
Time-frequency

- Example: Blink





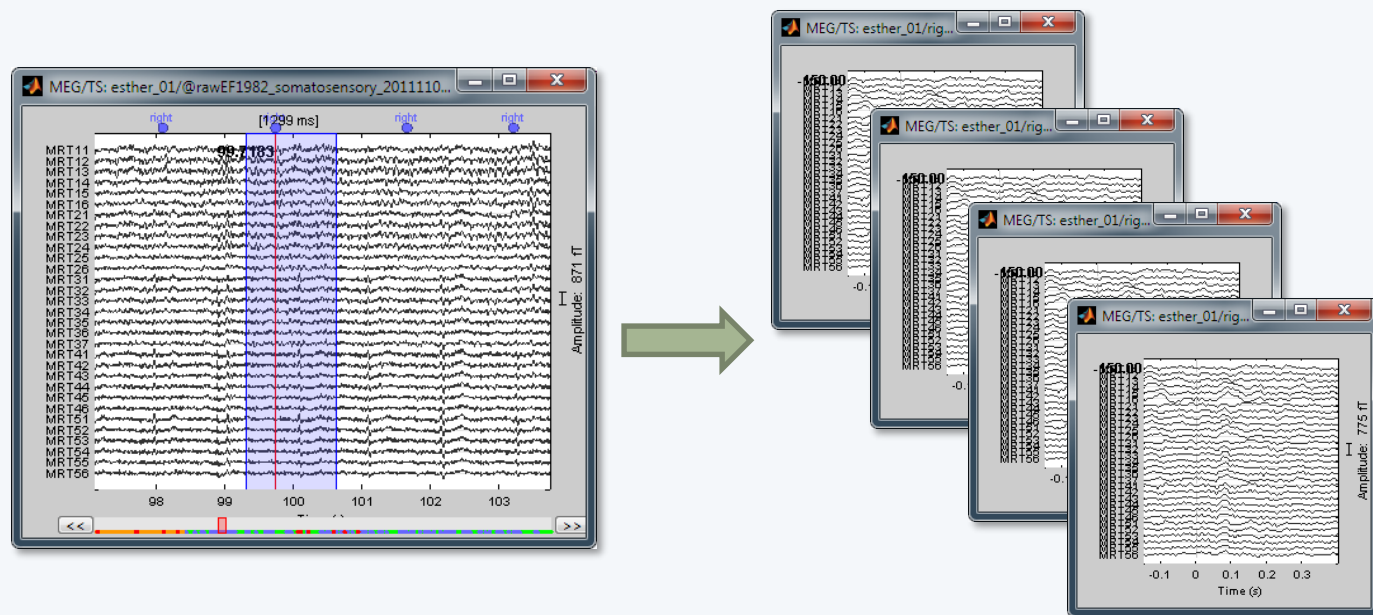
# Epoching

Anatomy  
Link recordings  
MRI registration

PSD  
Filters  
Bad channels  
Artifacts  
Correction  
Bad segments

Markers  
Epoching  
Combine  
**Extract**  
Length  
Process

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





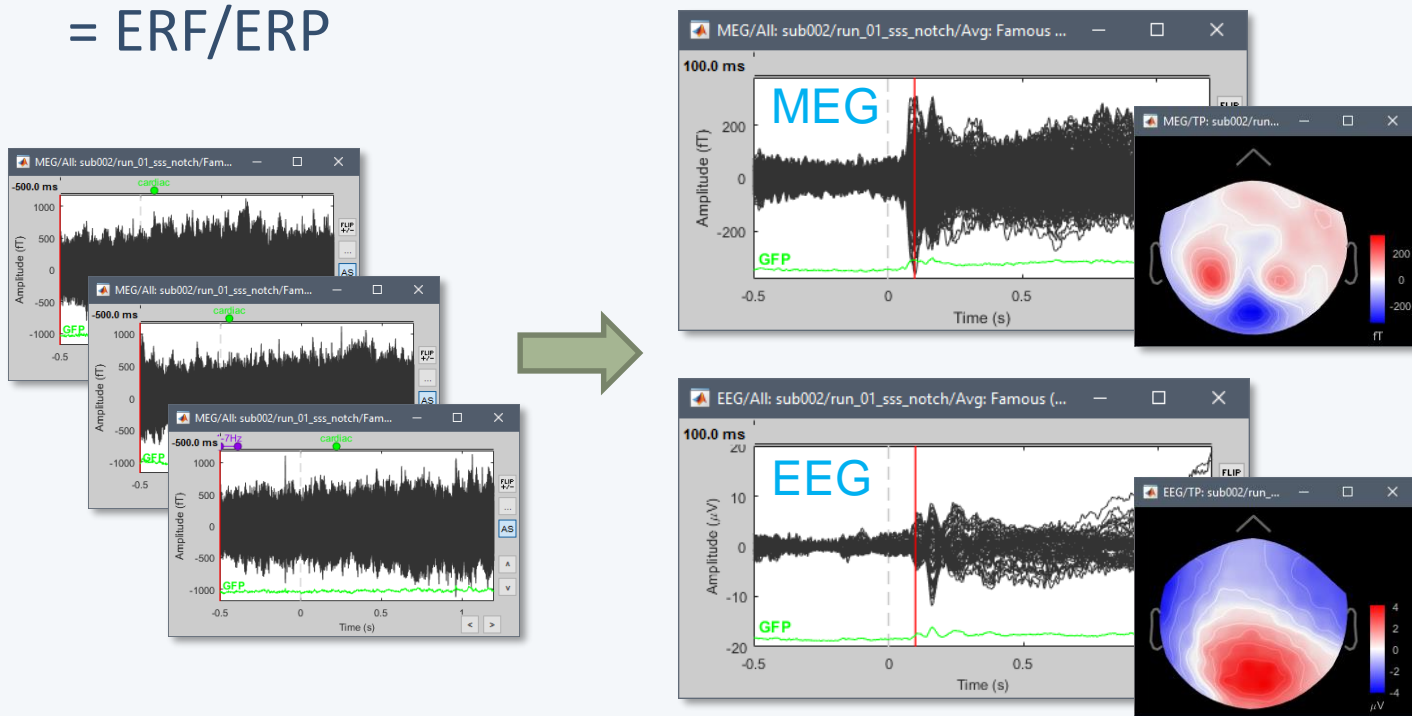
# Single subject

Anatomy  
Link recordings  
MRI registration

PSD  
Filters  
Bad channels  
Artifacts  
Correction  
Bad segments

Markers  
Epoching  
**Averaging**  
Sources  
Time-frequency

- 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





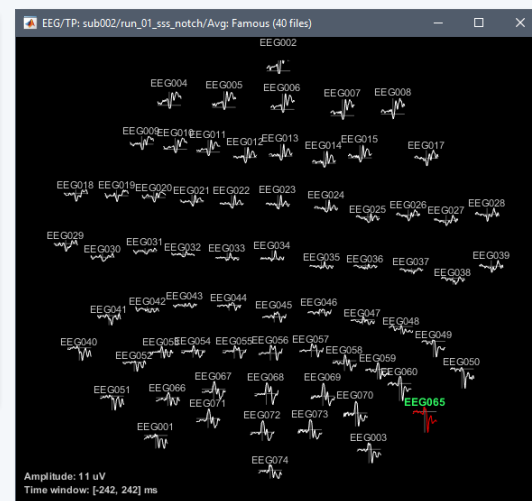
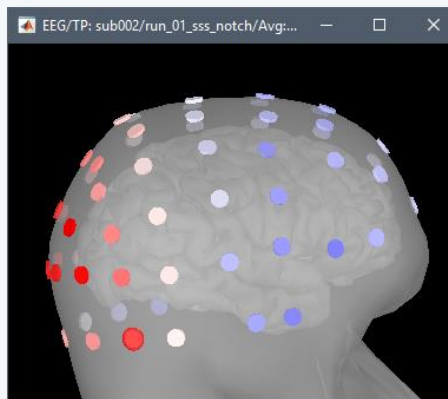
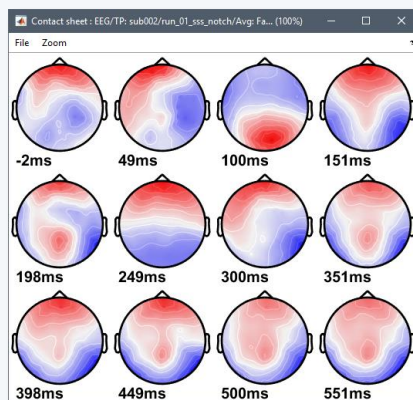
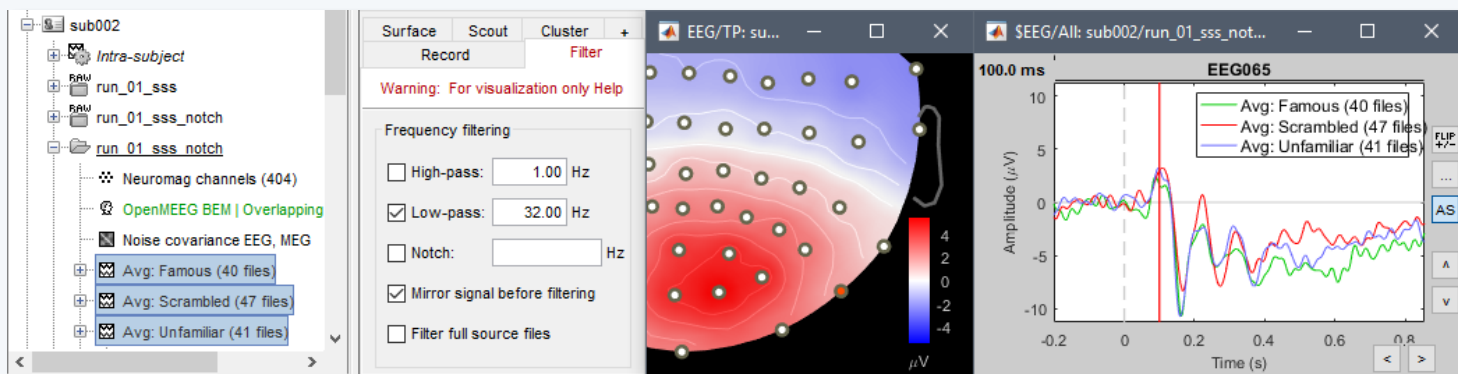
# Single subject

Anatomy  
Link recordings  
MRI registration

PSD  
Filters  
Bad channels  
Artifacts  
Correction  
Bad segments

Markers  
Epoching  
**Averaging**  
Sources  
Time-frequency

- EEG ERP: Famous faces





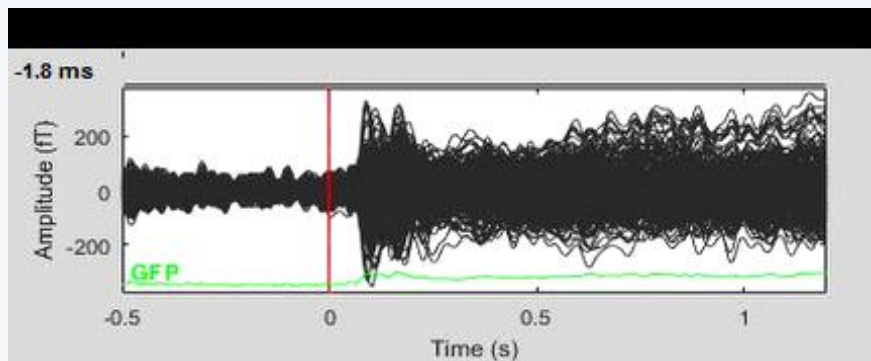
# Single subject

Anatomy  
Link recordings  
MRI registration

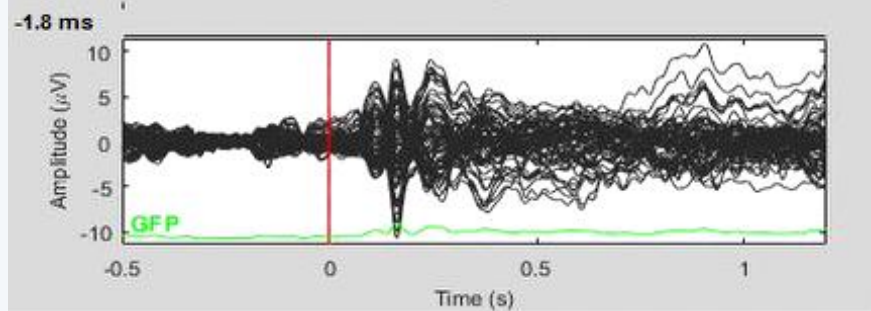
PSD  
Filters  
Bad channels  
Artifacts  
Correction  
Bad segments

Markers  
Epoching  
Averaging  
**Sources**  
Time-frequency

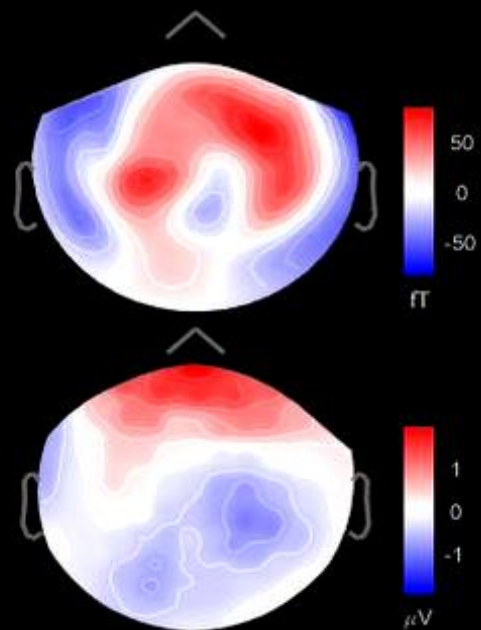
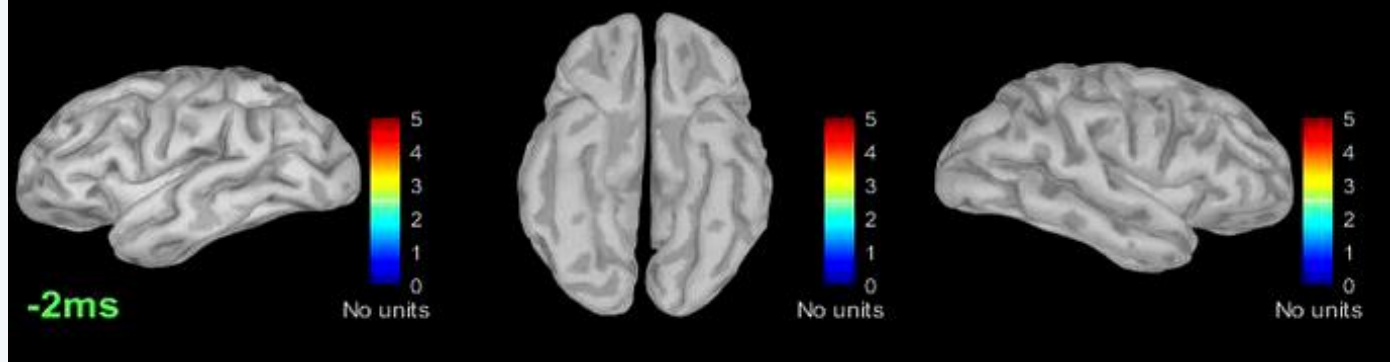
MEG



EEG



MEG sources





# Single subject

Anatomy  
Link recordings  
MRI registration

PSD

Filters

Bad channels

Artifacts

Correction

Bad segments

Markers

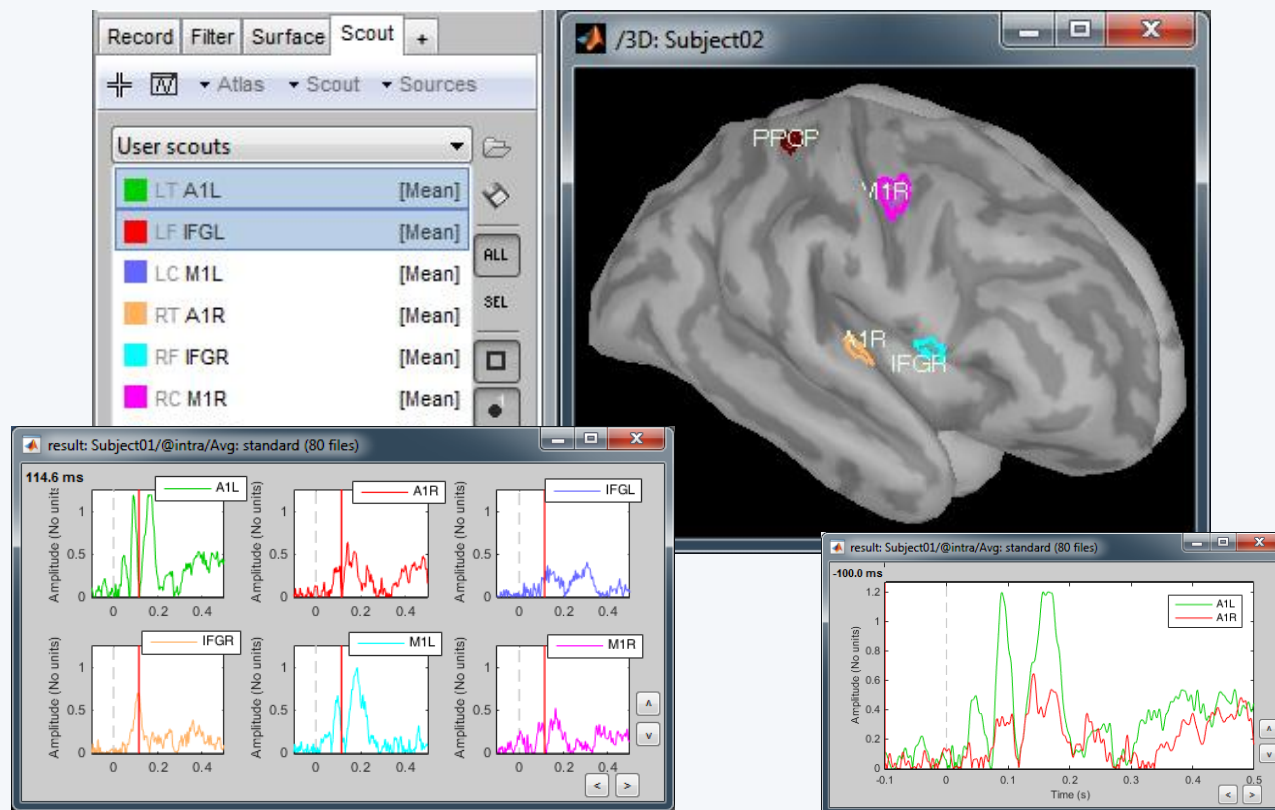
Epoching

Averaging

**Sources**

Time-frequency

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





# Single subject

Anatomy

Link recordings

MRI registration

PSD

Filters

Bad channels

Artifacts

Correction

Bad segments

Markers

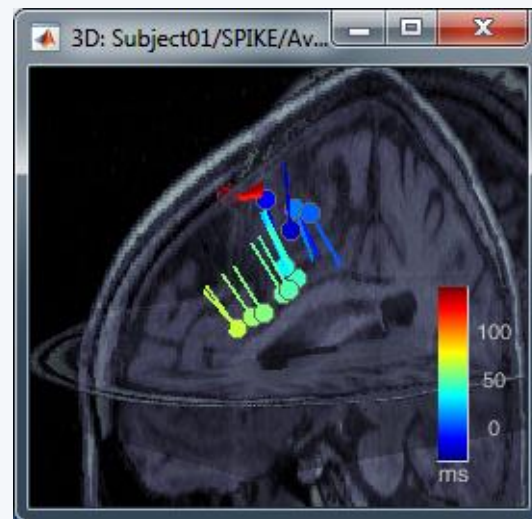
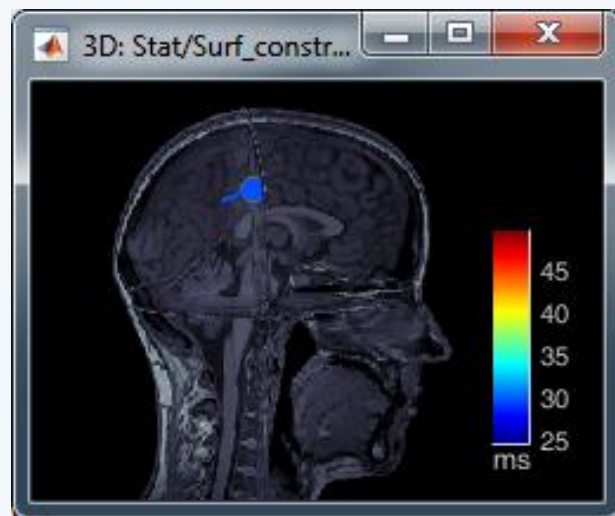
Epoching

Averaging

**Sources**

Time-frequency

- **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)



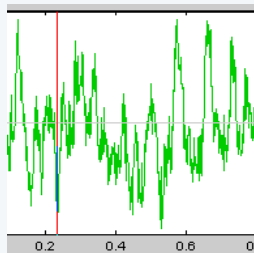


# Single subject

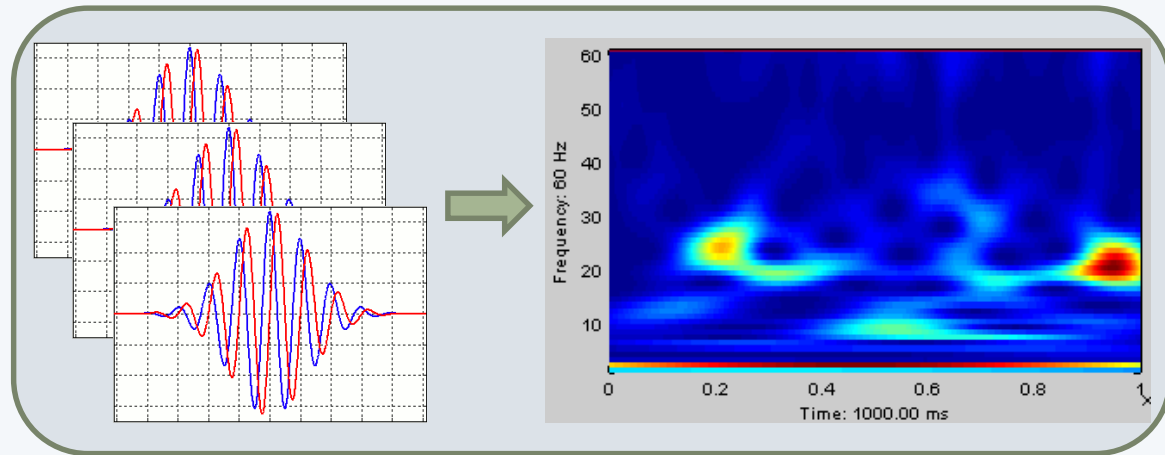
Anatomy  
Link recordings  
MRI registration

PSD  
Filters  
Bad channels  
Artifacts  
Correction  
Bad segments

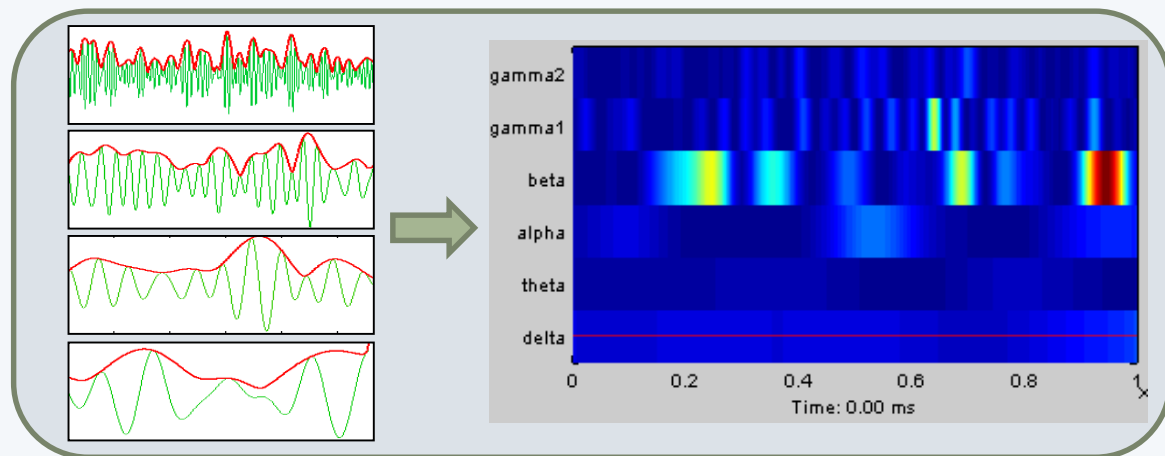
Markers  
Epoching  
Averaging  
Sources  
**Time-frequency**



## Morlet wavelets



## Hilbert transform + band-pass filter





# Group analysis

Subject averages

Low-pass

Normalize

Project

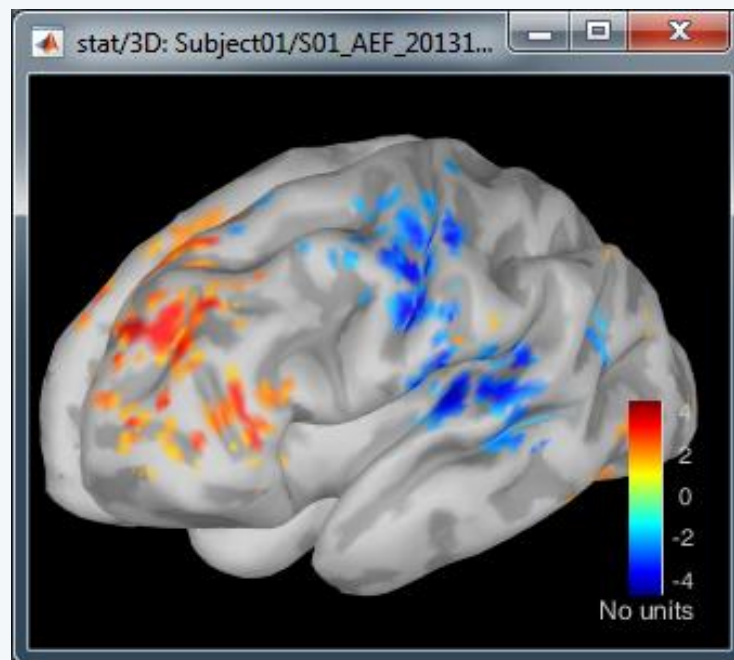
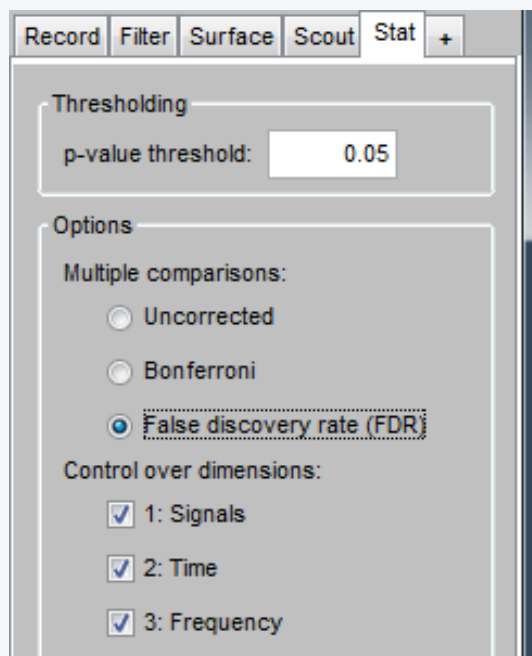
Group averages

**Group statistics**

Quality control

Workflow

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





# Group analysis

Subject averages

Low-pass

Normalize

Project

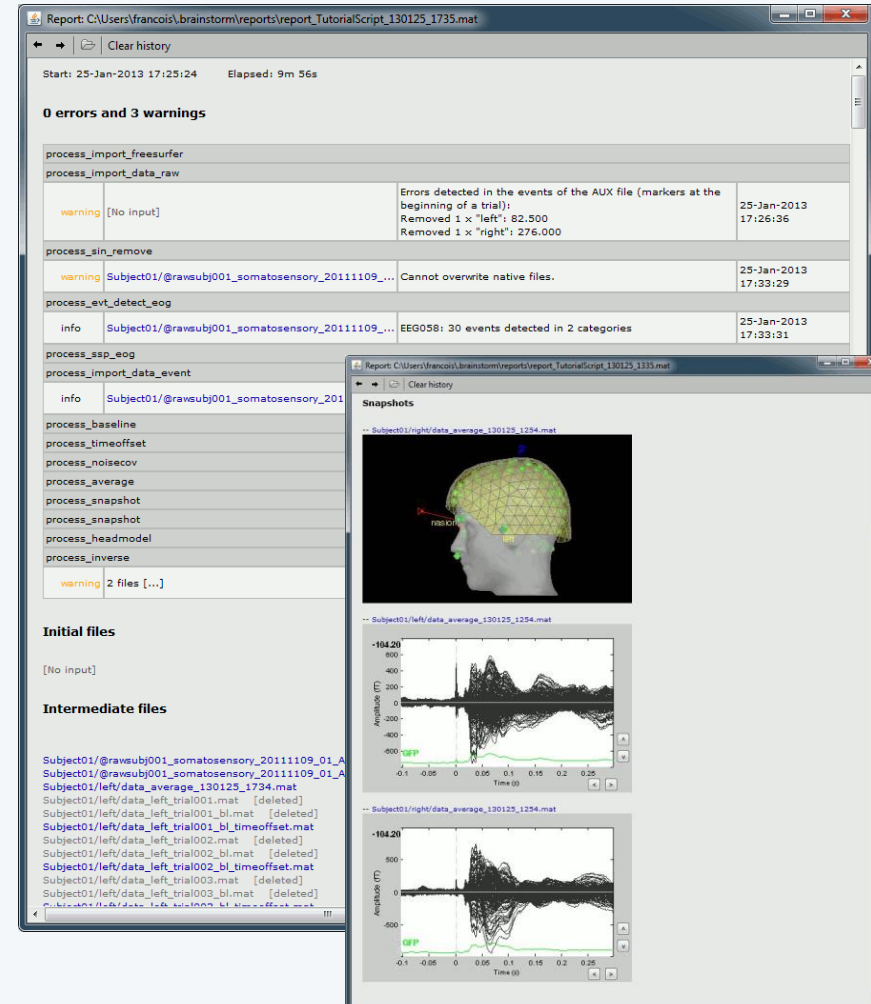
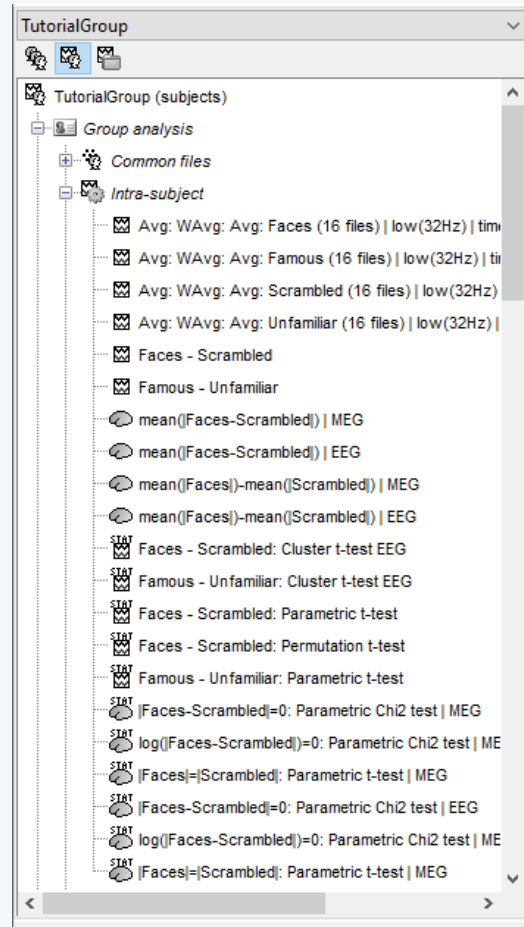
Group averages

Group statistics

Quality control

Workflow

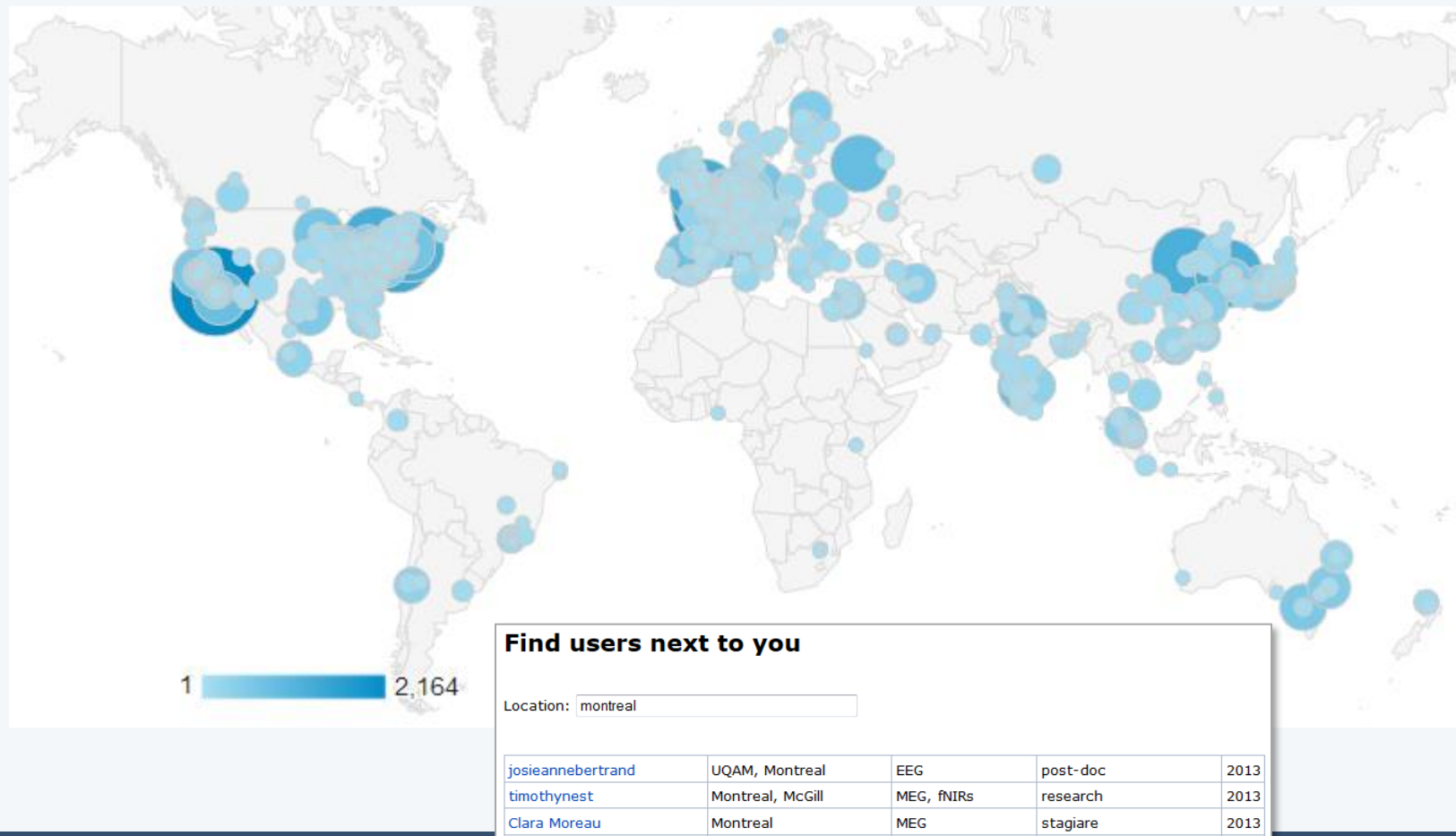
- Execution reports with snapshots saved in HTML





# User community

- 24,000 users registered on the website
- 230 publications using Brainstorm per year





# User support

- Online tutorials: 30-hour self-training program
- Active user forum: 400 posts/month
- Daily updates: 1400 downloads/month



The screenshot shows the Brainstorm website's home page. At the top is the Brainstorm logo and a search bar. Below the logo is a navigation menu with categories: Software, Users, and Development. The 'Software' section includes links for Introduction, Gallery, Download, and Installation. The 'Users' section includes Tutorials, Forum, Courses, Community, and Publications. The 'Development' section includes 'What's new'. The main content area is titled 'Get started' and is divided into three columns: 'Starting a new study', 'Reviewing', and 'Pre-processing'. Each column contains a list of numbered links to various tutorials and guides. For example, 'Starting a new study' includes 'Create a new protocol', 'Import the subject anatomy', and 'Explore the anatomy'. 'Reviewing' includes 'Channel file / MRI registration', 'Continuous recordings', 'Multiple windows', and 'Event markers'. 'Pre-processing' includes 'Stimulation delays', 'Select files / Run processes', 'Power spectrum / Frequency filters', 'Bad channels', 'Artifact detection', 'Artifact cleaning with SSP', and 'Additional bad segments'. There are also sections for 'Epoching and averaging', 'Source modeling', and 'Advanced processing'.

**Brainstorm** Edit Search

**Get started**

**Starting a new study**

1. Create a new protocol [9]
2. Import the subject anatomy [8]
3. Explore the anatomy [13]

**Reviewing**

4. Channel file / MRI registration [11]
5. Continuous recordings [9]
6. Multiple windows [5]
7. Event markers [10]

**Pre-processing**

8. Stimulation delays [9]
9. Select files / Run processes [11]
10. Power spectrum / Frequency filters [15]
11. Bad channels [6]
12. Artifact detection [8]
13. Artifact cleaning with SSP [16]
14. Additional bad segments [7]

**Epoching and averaging**

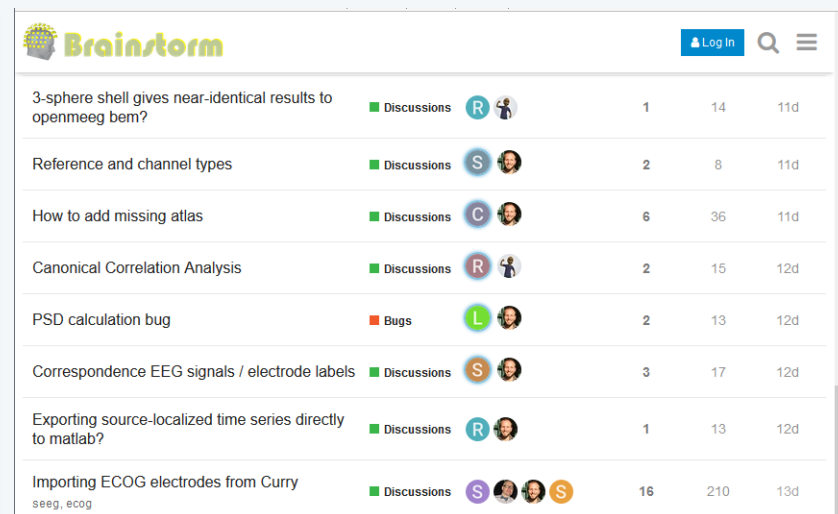
15. Import epochs [9]
16. Average response [7]
17. Visual exploration [10]
18. Colormaps [5]
19. Clusters of sensors [4]

**Source modeling**

20. Head model [9]
21. Noise/data covariance
22. Source estimation [28]
23. Scouts [17]

**Advanced processing**

24. Time-frequency [33]
25. Difference [13]
26. Statistics [30]
27. Workflows [10]
28. Scripting [31]



The screenshot shows the Brainstorm forum page. At the top is the Brainstorm logo and a 'Log In' button. Below the logo is a table of forum posts. Each row represents a post with its title, category, status, author, and statistics (number of replies, views, and time since posted). The posts include '3-sphere shell gives near-identical results to openmeeg bem?', 'Reference and channel types', 'How to add missing atlas', 'Canonical Correlation Analysis', 'PSD calculation bug', 'Correspondence EEG signals / electrode labels', 'Exporting source-localized time series directly to matlab?', and 'Importing ECOG electrodes from Curry seeg, ecog'.

**Brainstorm** Log In

3-sphere shell gives near-identical results to openmeeg bem?	Discussions	R	1	14	11d
Reference and channel types	Discussions	S	2	8	11d
How to add missing atlas	Discussions	C	6	36	11d
Canonical Correlation Analysis	Discussions	R	2	15	12d
PSD calculation bug	Bugs	L	2	13	12d
Correspondence EEG signals / electrode labels	Discussions	S	3	17	12d
Exporting source-localized time series directly to matlab?	Discussions	R	1	13	12d
Importing ECOG electrodes from Curry seeg, ecog	Discussions	S	16	210	13d





# Contributors

## Investigators



Sylvain Baillet  
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Richard Leahy  
*USC*



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*Cleveland Clinic*



Dimitrios Pantazis  
*MIT*

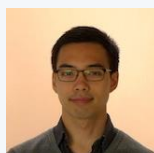
## MEG @ McGill



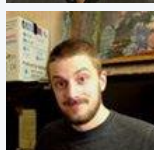
Konstantinos Nasiotis  
*PhD student*



Soheila Samiee  
*PhD student*



Jeremy Moreau  
*PhD student*

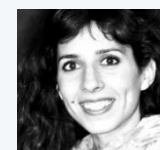


Peter Donhauser  
*PhD student*

## Key collaborators



Elizabeth Bock  
*MEGIN, Chicago*



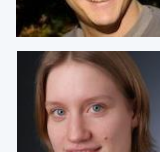
Guiomar Niso  
*Politécnica Madrid*



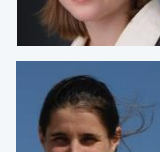
Guiomar Niso  
*Politécnica Madrid*



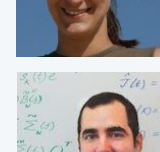
Alexandre Gramfort  
*Telecom / Neurospin*



Esther Florin  
*Univ Hosp Cologne*



Anne-Sophie Dubarry  
*Aix-Marseille Univ*



Rey Ramirez  
*UW*

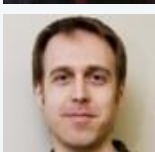
## Geeks



François Tadel  
*Software, Grenoble*

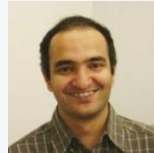


Martin Cousineau  
*Software, MNI*



Marc Lalancette  
*MEG manager, MNI*

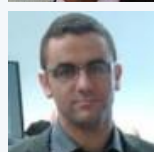
## SIPI @ USC



Anand Joshi  
*Res Assist Professor*



Hossein Shahabi  
*Research assistant*



Takfarinas Medani  
*Research assistant*



## Visual recognition task

- Faces presentation: Famous / Unfamiliar / Scrambled
- 1 participant / 1 run / 50 trials per condition
- 400-600ms fixation cross, 800-1000 stim, 1700ms ISI  
Total 10min per run
- Elekta-Neuromag VectorView system (MEG+EEG)  
102 magnetometers, 204 gradiometers, 70 electrodes
- Recorded at 1100Hz
- Individual MRI, anonymized, processed with FreeSurfer 5.3

