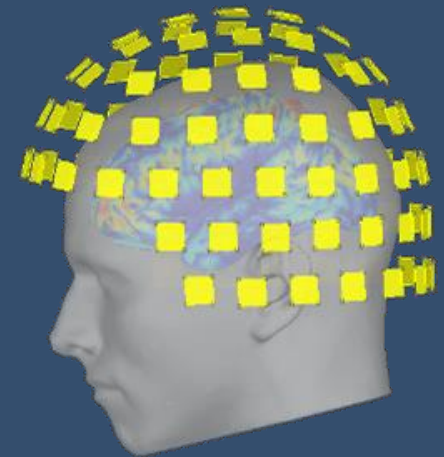


SEEG analysis using

Brainstorm

<http://neuroimage.usc.edu/brainstorm>



neuro

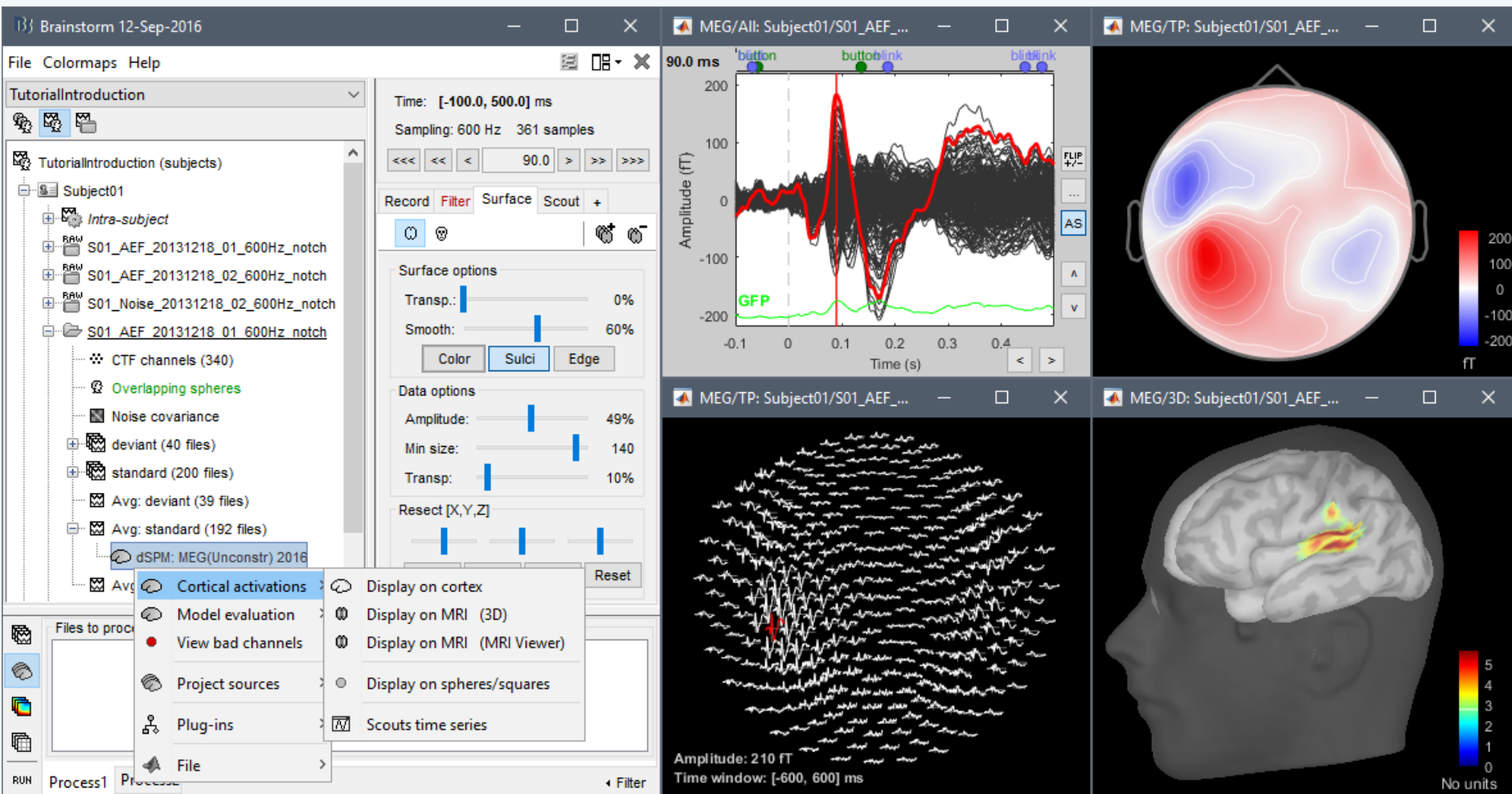


UTHealth

CuttingEEG 2021

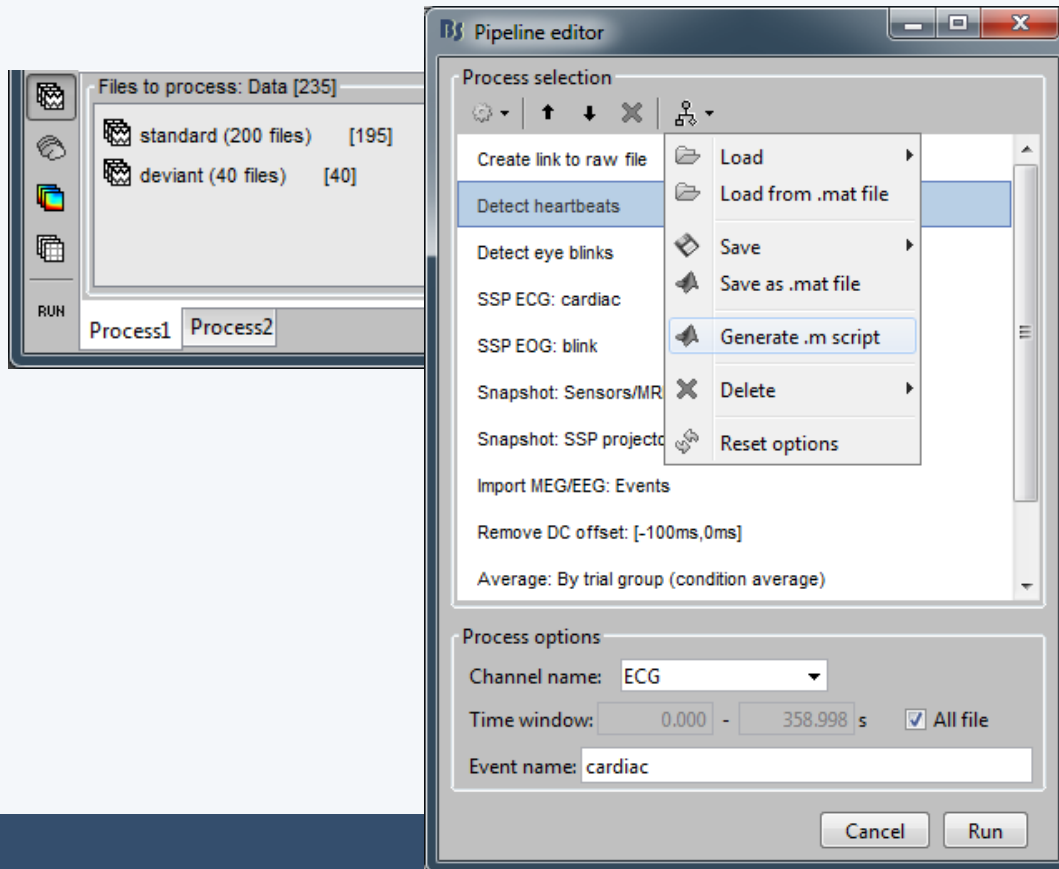
Francois Tadel

Graphic interface



Scripting environment

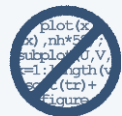
- Rapid selection of files and processes to apply
- Automatic generation of Matlab scripts
- Plug-in structure: easy to add custom processes



```
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);
```

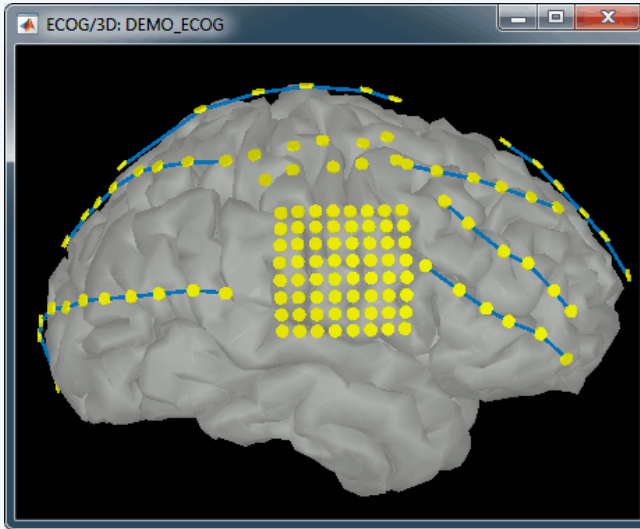
Brainstorm

- 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

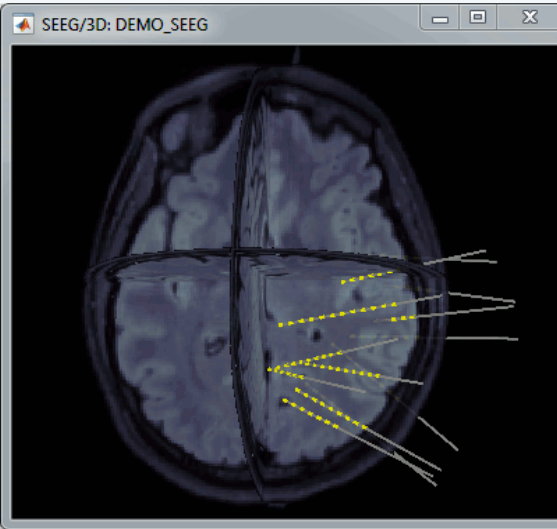


Multi-modal imaging

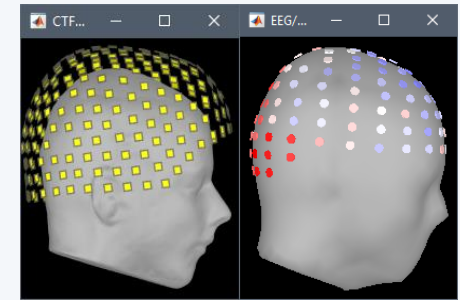
ECoG



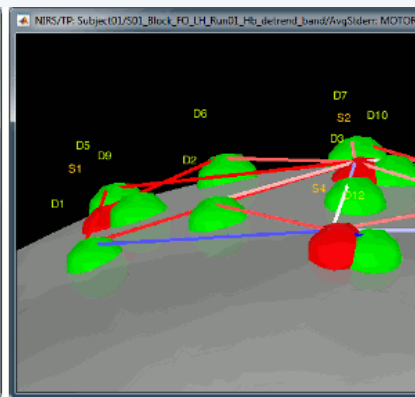
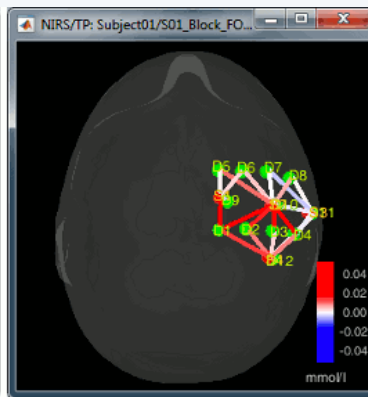
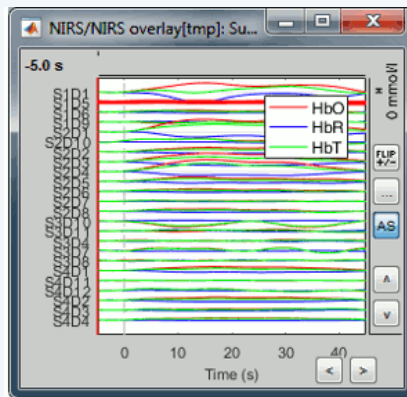
Depth electrodes



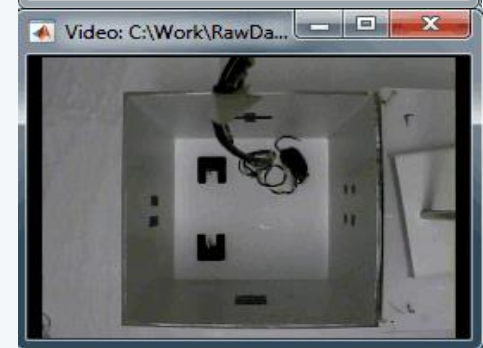
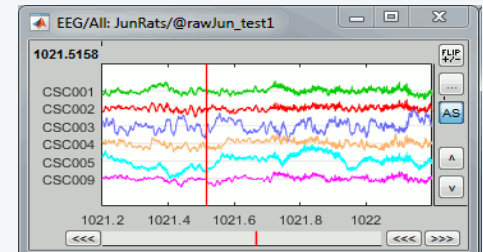
MEG/EEG



fNIRS

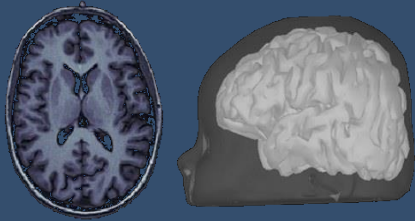


Electrophysiology

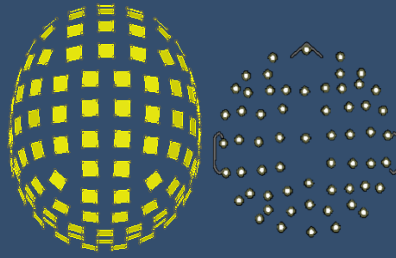


Workflow

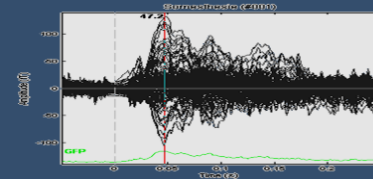
Anatomy



Sensors



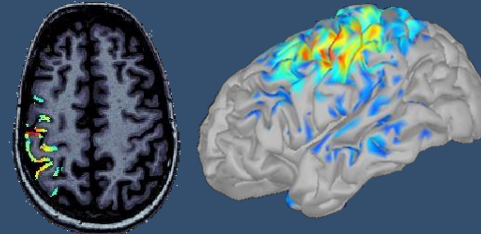
EEG/MEG



Co-registration



Source estimation



Analysis

Averages
Contrasts
Group analysis
Time-frequency
Connectivity

Import

Anatomy

Link recordings
MRI registration

PSD

Filters

Bad channels

Artifacts

Correction

Bad segments

Markers

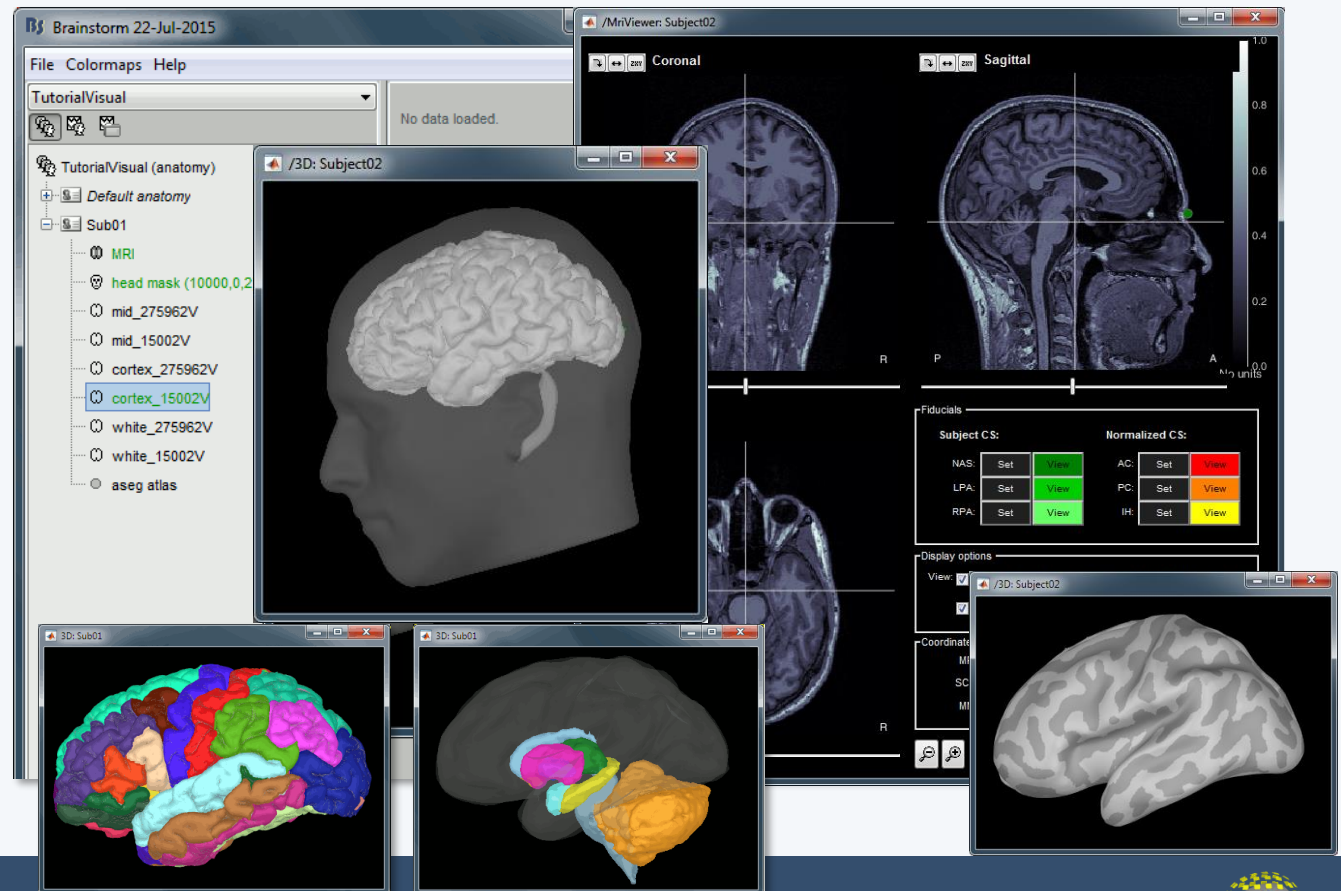
Epoching

Averaging

Sources

Time-frequency

- One-click import of the T1 segmentation: FreeSurfer, CAT12, BrainSuite, BrainVISA, SimNIBS
- Full integration for running CAT12 and SimNIBS



Anatomy

Link recordings
MRI registration

PSD

Filters

Bad channels

Artifacts

Correction

Bad segments

Markers

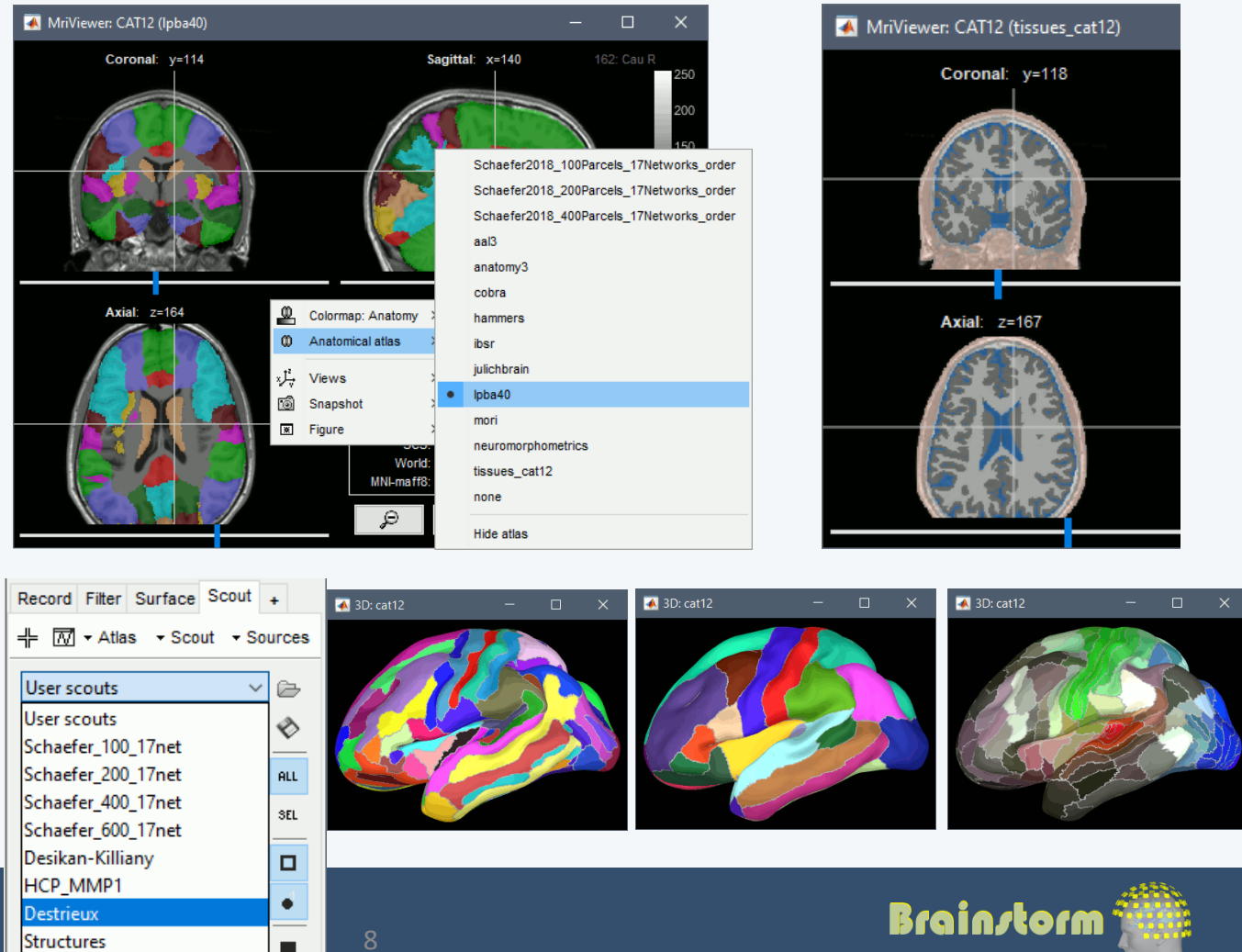
Epoching

Averaging

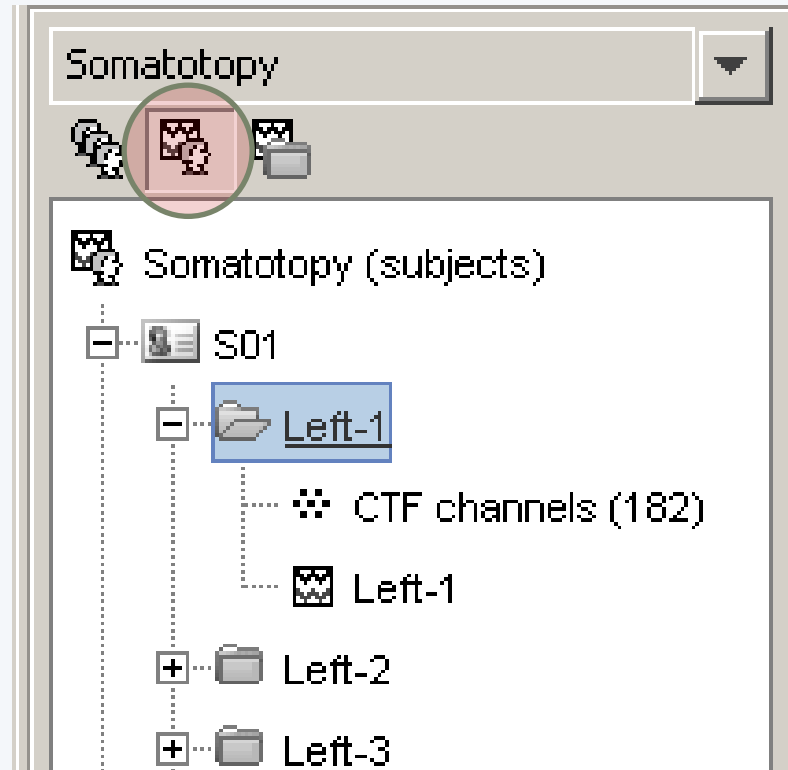
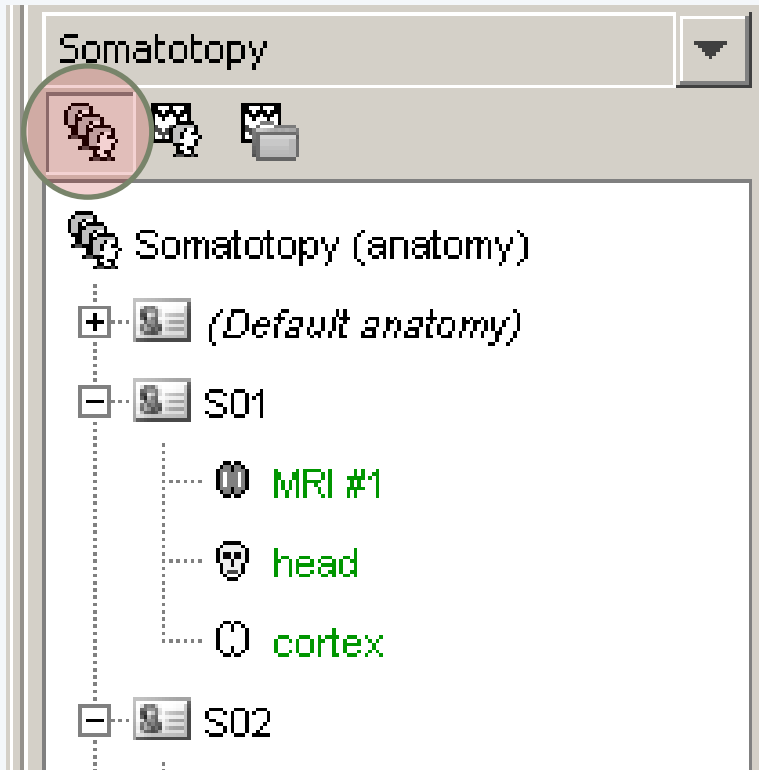
Sources

Time-frequency

- Anatomical parcellations: Volume and surface
- MNI normalization: linear and non-linear (SPM12)



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

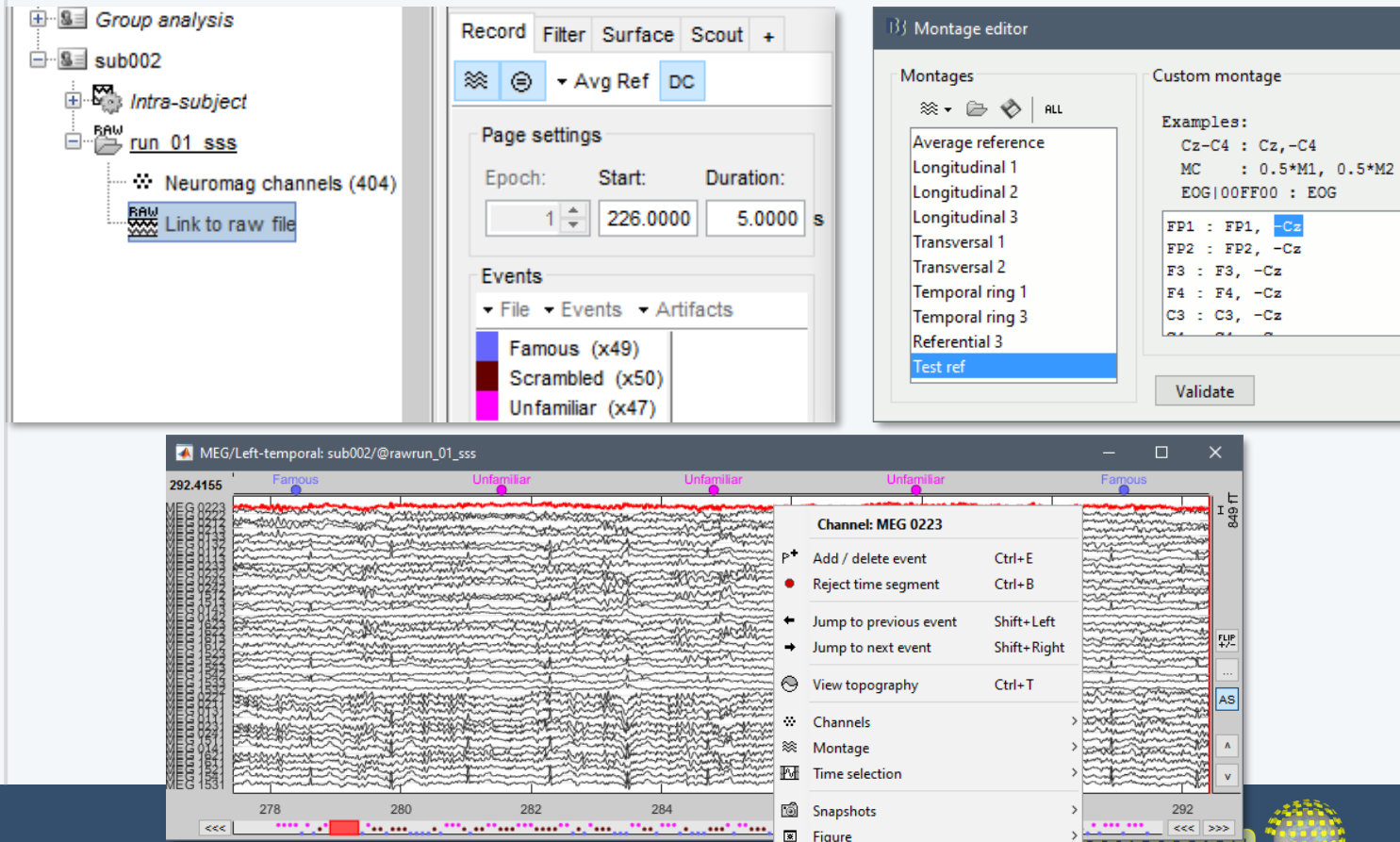
Epoching

Averaging

Sources

Time-frequency

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



Quality control

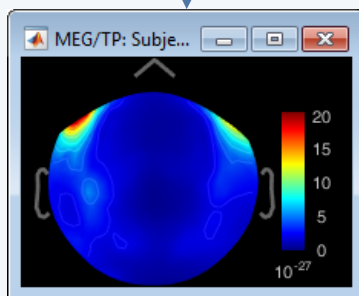
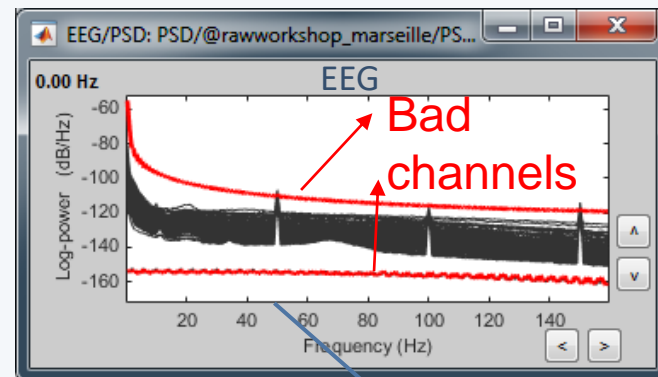
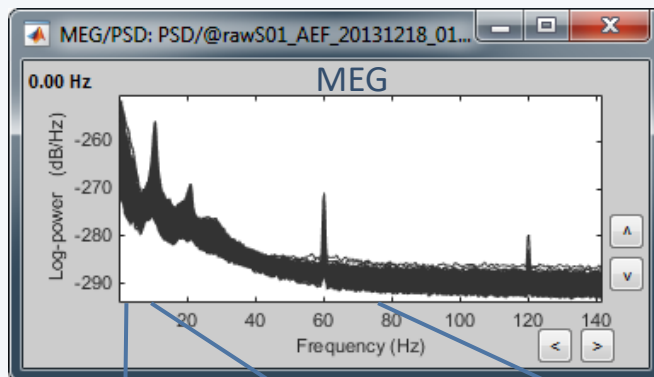
Anatomy
Link recordings
MRI registration

PSD

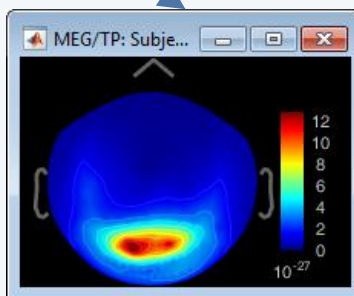
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency

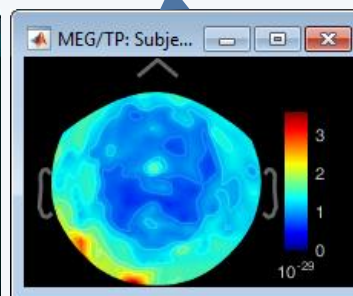
- Power spectrum density for quality control



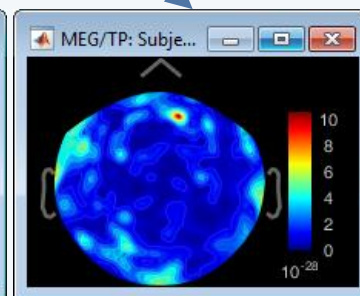
< 3Hz: Eyes



10Hz: Alpha



> 40Hz: Muscle



50/60Hz

Pre-processing

Anatomy
Link recordings
MRI registration

PSD

Filters

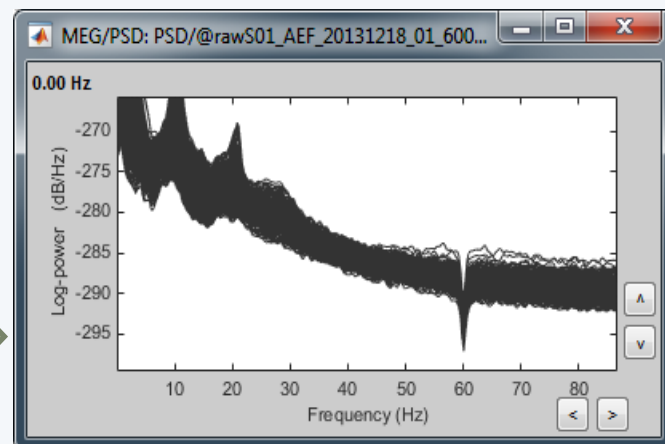
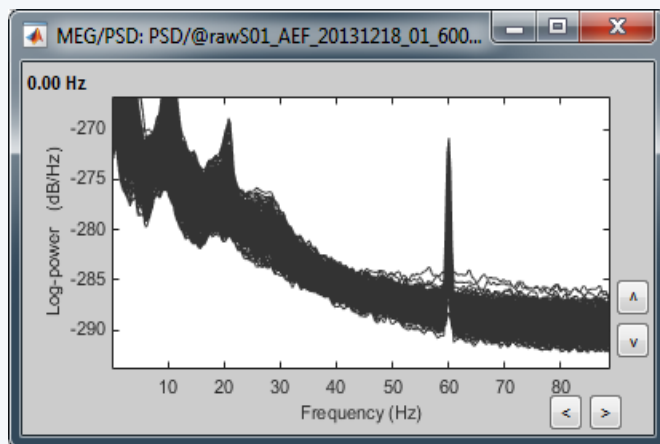
Bad channels
Artifacts
Correction
Bad segments

Markers

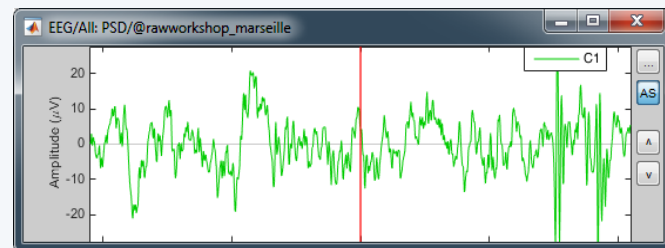
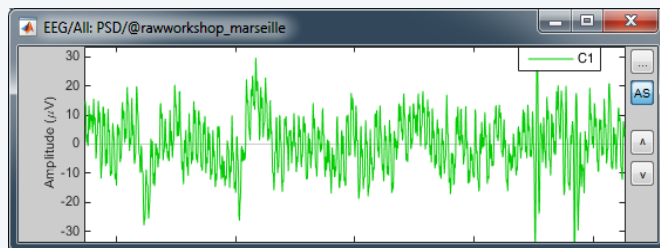
Epoching
Averaging
Sources
Time-frequency

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

PSD



Signal



Pre-processing

Anatomy
Link recordings
MRI registration

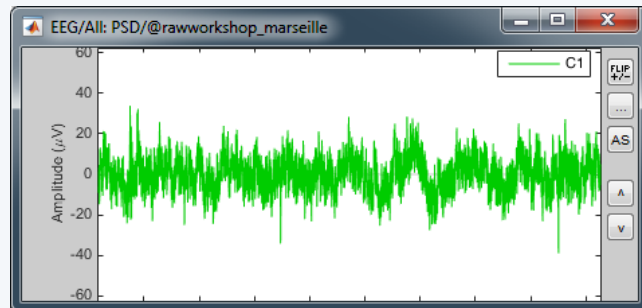
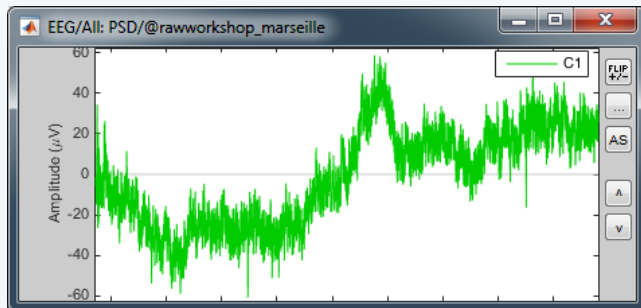
PSD

Filters

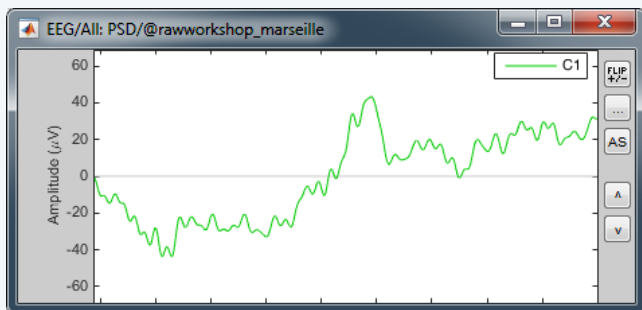
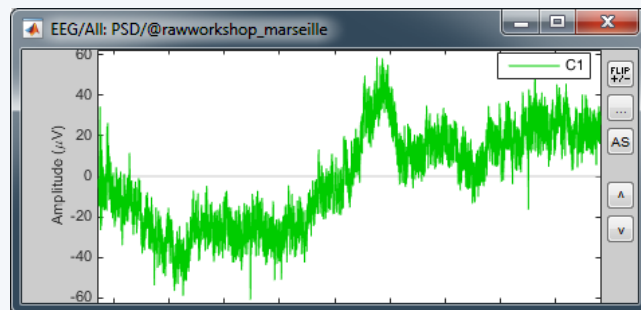
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency

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



- Low-pass filter: Remove high-frequencies



Pre-processing

Anatomy
Link recordings
MRI registration

PSD

Filters

Bad channels

Artifacts

Correction

Bad segments

Markers

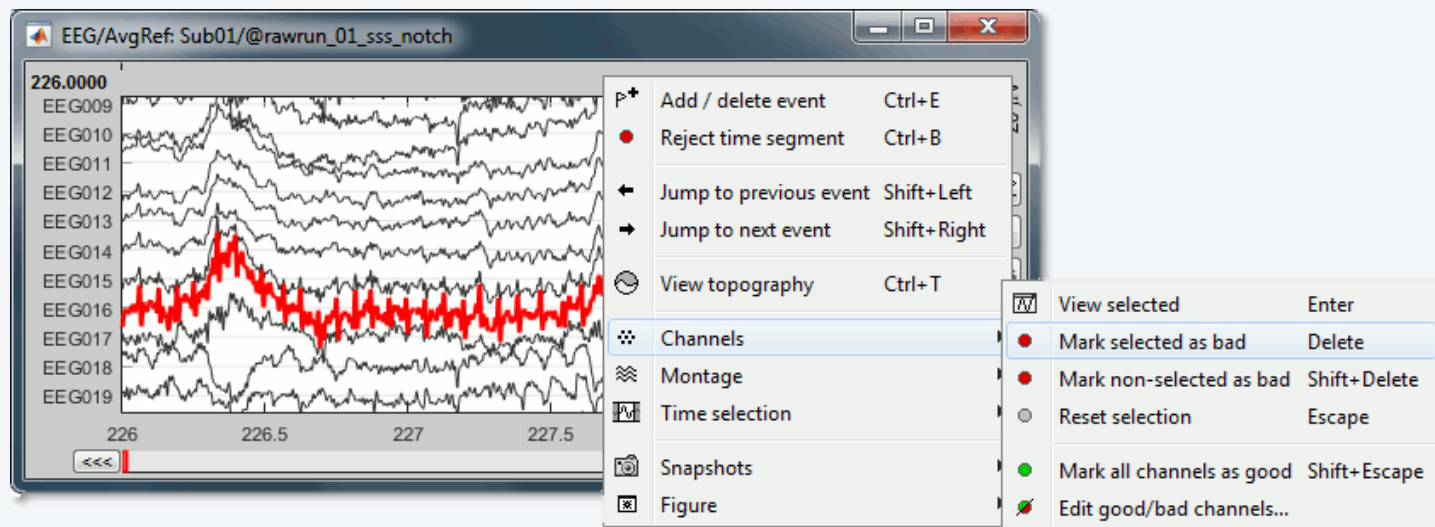
Epoching

Averaging

Sources

Time-frequency

- Manual inspection of the recordings
- Interactive selection of bad channels
- Re-reference the EEG if necessary



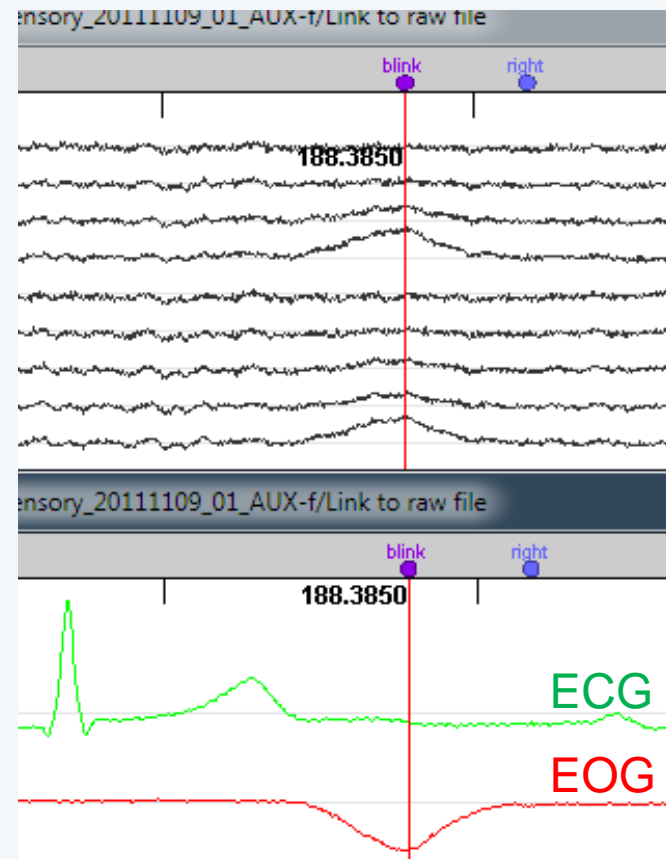
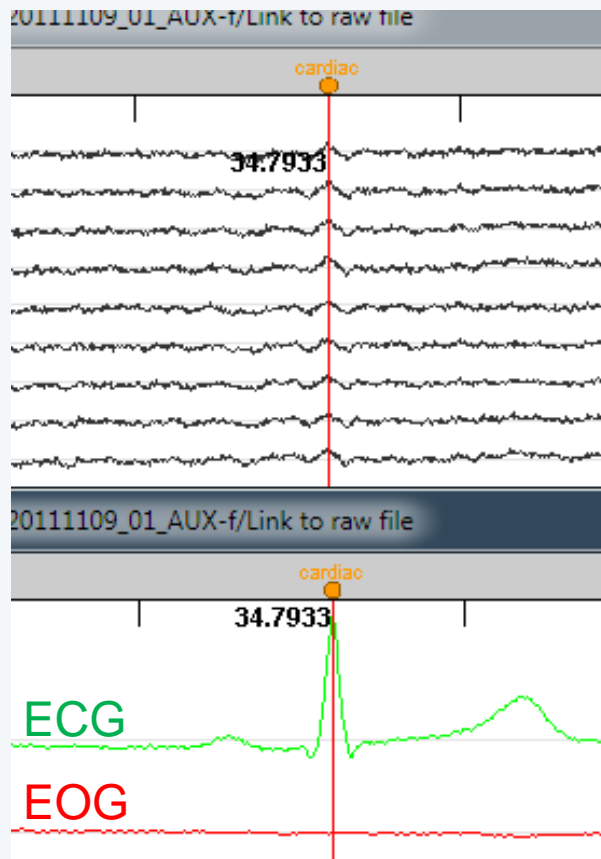
Pre-processing

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)



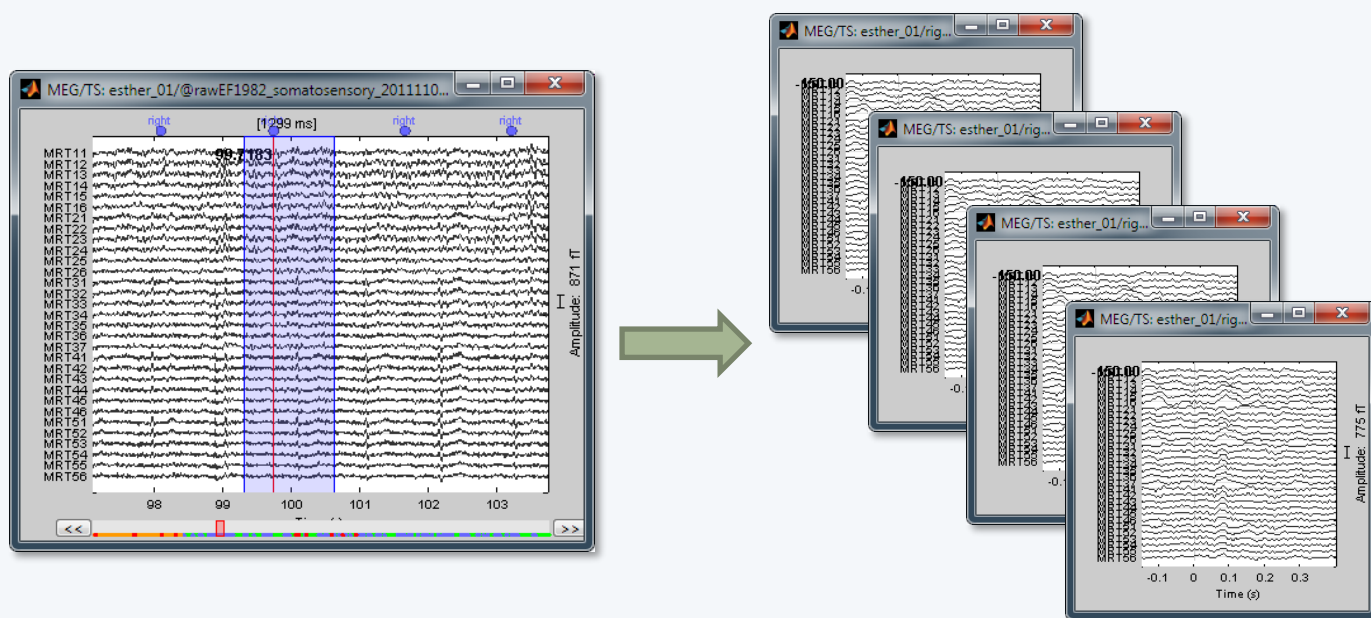
Epoching

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.



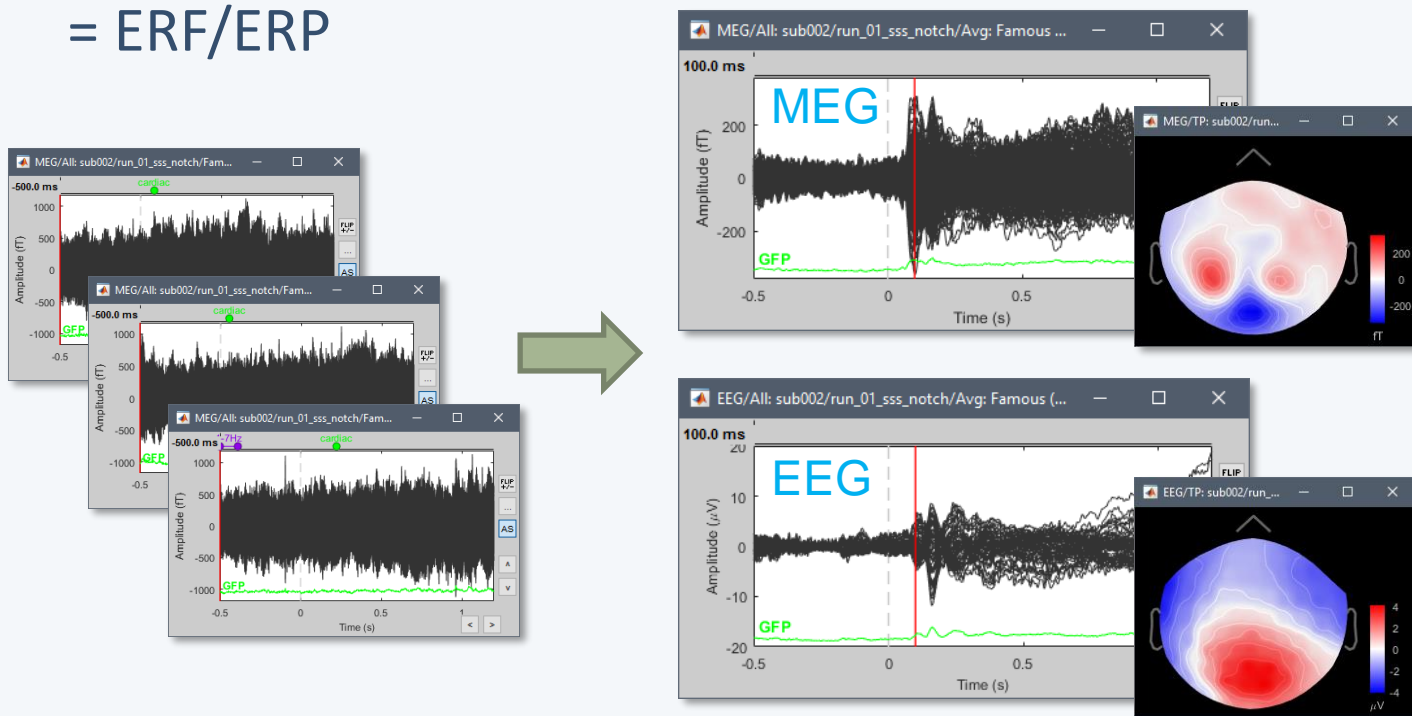
Single subject

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



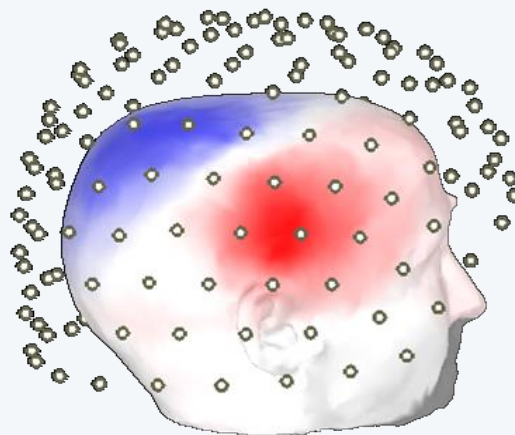
Single subject

Anatomy
Link recordings
MRI registration

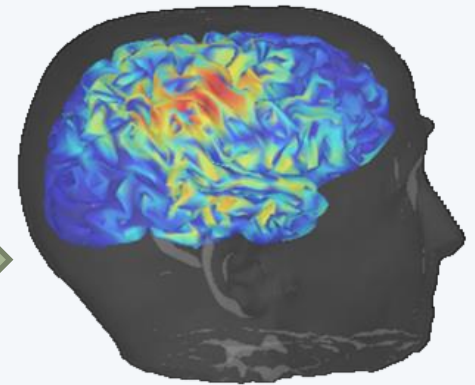
PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency

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

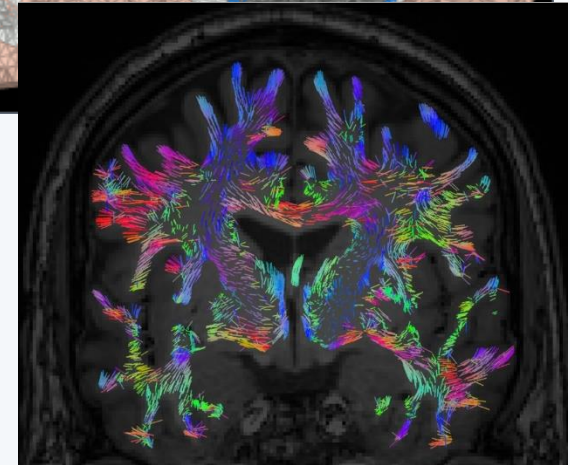
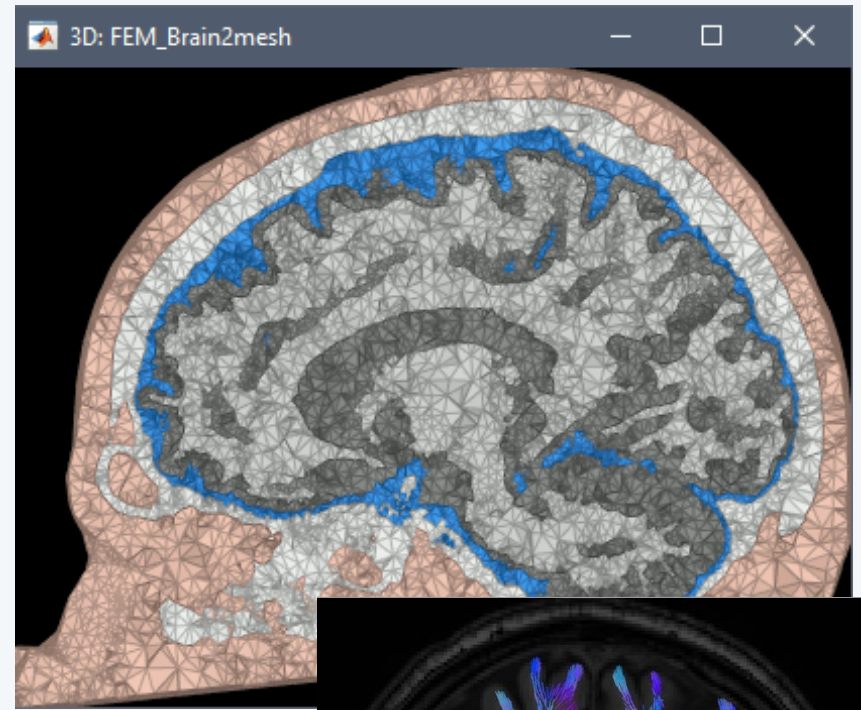
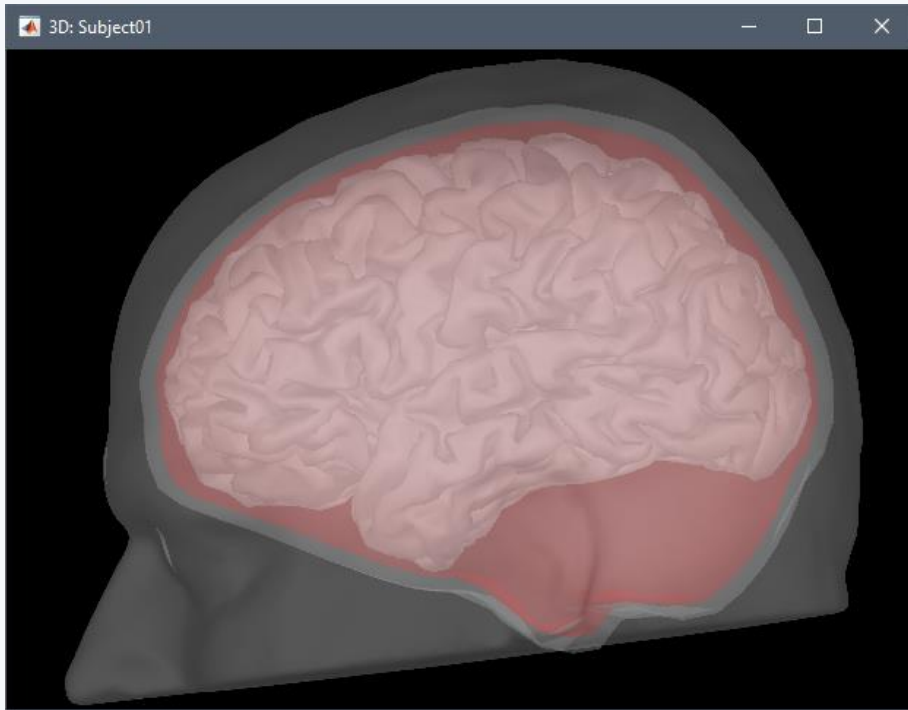


Sensor space



Source space

forward modelling



BEM: Tissue boundaries = triangular surfaces

FEM: Volume elements = tetrahedrons
+ anisotropy from DTI (white matter)

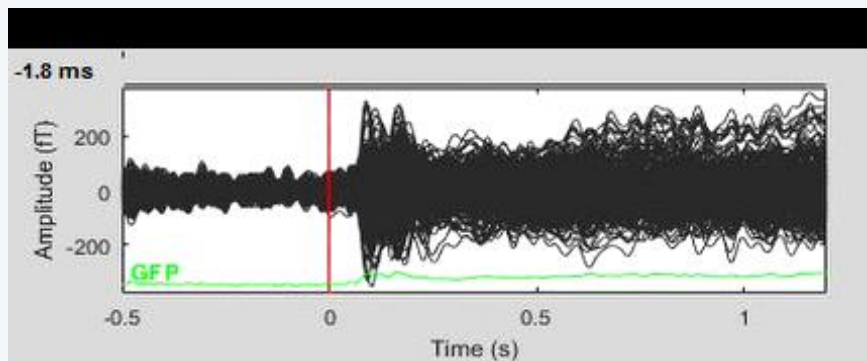
Single subject

Anatomy
Link recordings
MRI registration

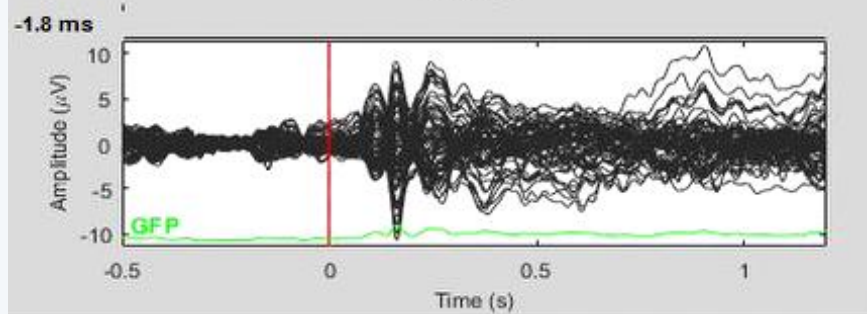
PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency

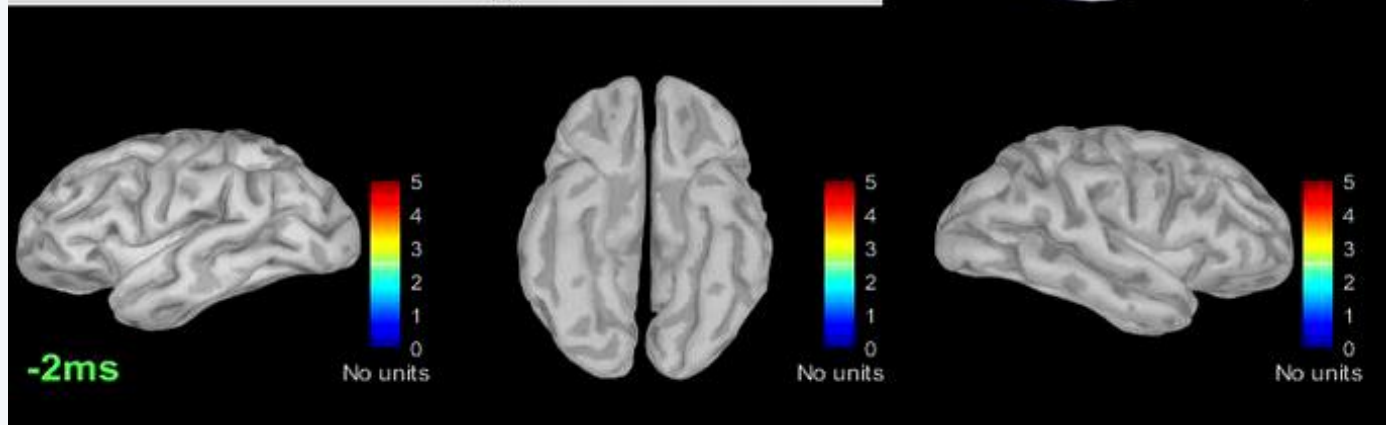
MEG



EEG



MEG sources



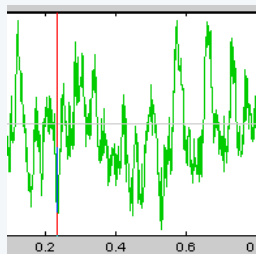
Famous faces

Single subject

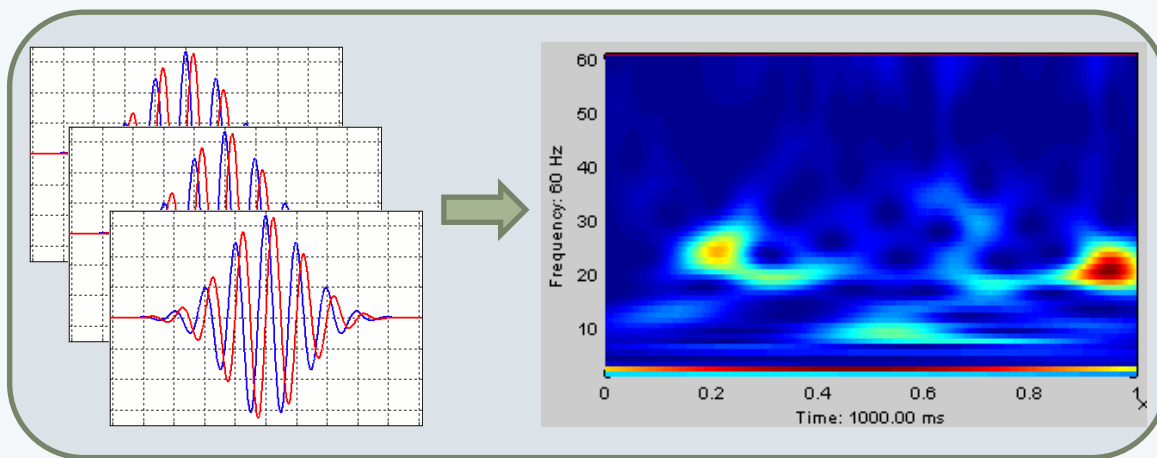
Anatomy
Link recordings
MRI registration

PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

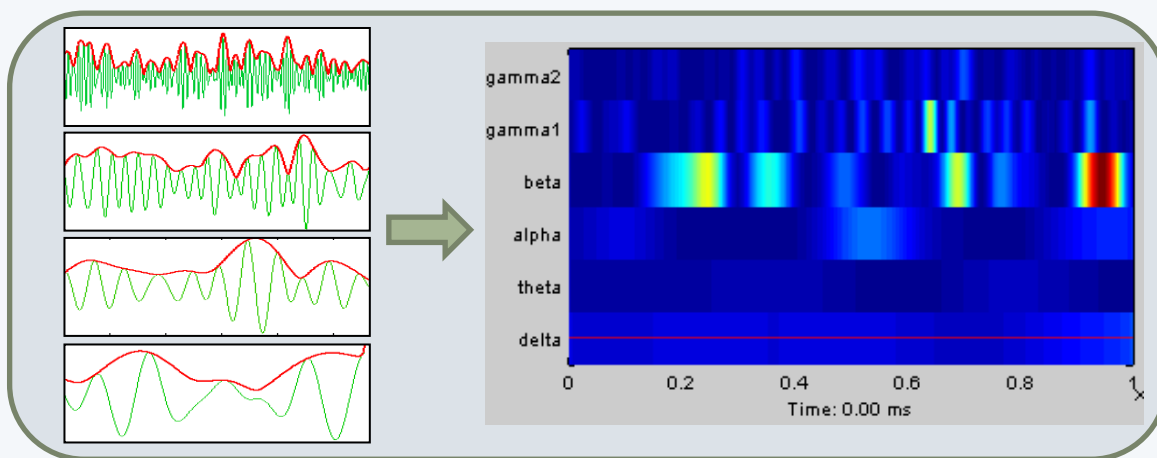
Markers
Epoching
Averaging
Sources
Time-frequency



Morlet wavelets



Hilbert transform + band-pass filter



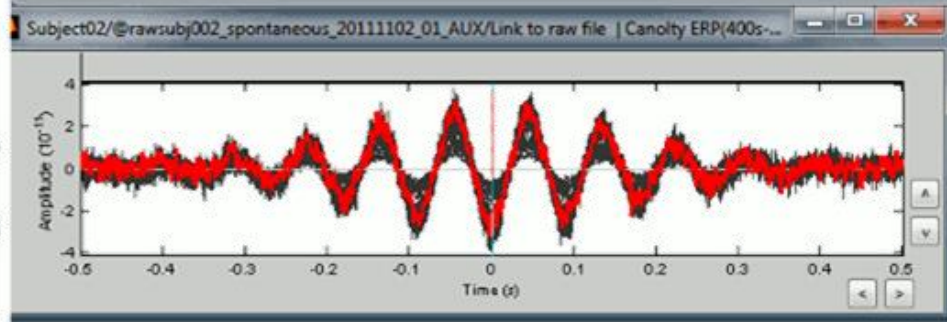
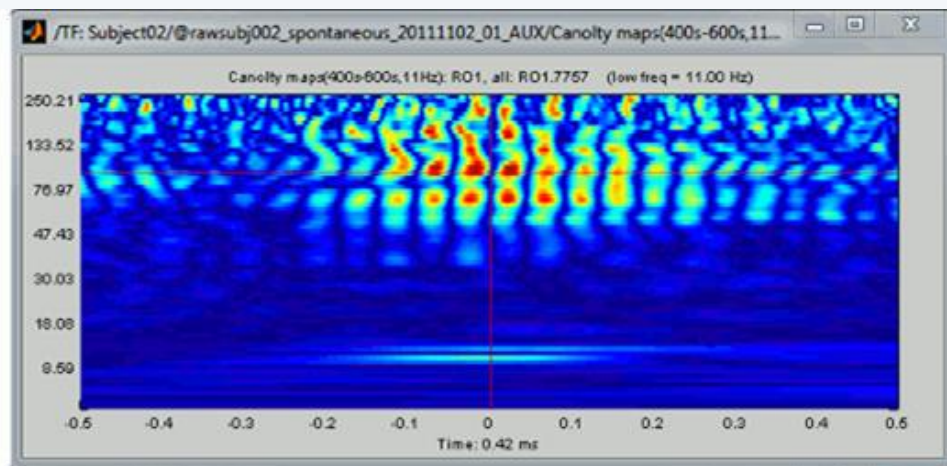
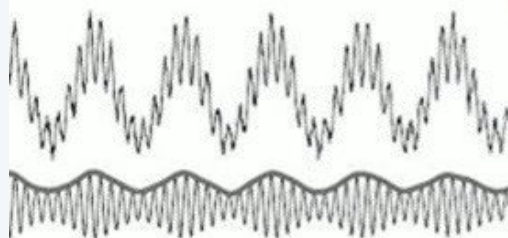
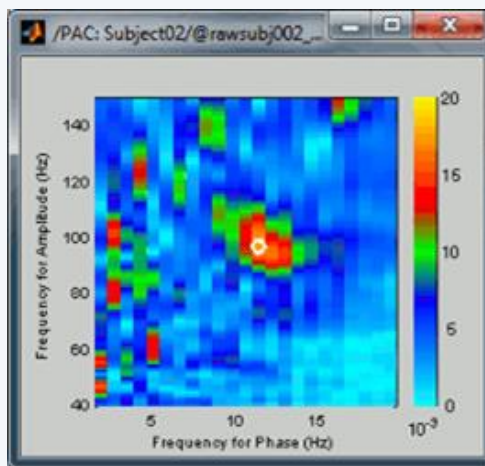
Single subject

Anatomy
Link recordings
MRI registration

PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency
Other measures

- Phase-amplitude coupling



Group analysis

Subject averages

Low-pass

Normalize

Project

Group averages

Group statistics

Quality control

Workflow

- Execution reports with snapshots saved in HTML

TutorialGroup (subjects)

- Group analysis
 - Common files
 - Intra-subject
 - Avg: WAvg: Avg: Faces (16 files) | low(32Hz) | tim
 - Avg: WAvg: Avg: Famous (16 files) | low(32Hz) | ti
 - Avg: WAvg: Avg: Scrambled (16 files) | low(32Hz)
 - Avg: WAvg: Avg: Unfamiliar (16 files) | low(32Hz) |
 - Faces - Scrambled
 - Famous - Unfamiliar
 - mean(|Faces-Scrambled|) | MEG
 - mean(|Faces-Scrambled|) | EEG
 - mean(|Faces|)-mean(|Scrambled|) | MEG
 - mean(|Faces|)-mean(|Scrambled|) | EEG
 - Faces - Scrambled: Cluster t-test EEG
 - Famous - Unfamiliar: Cluster t-test EEG
 - Faces - Scrambled: Parametric t-test
 - Faces - Scrambled: Permutation t-test
 - Famous - Unfamiliar: Parametric t-test
 - |Faces-Scrambled|=0: Parametric Chi2 test | MEG
 - log(|Faces-Scrambled|)=0: Parametric Chi2 test | ME
 - |Faces|=Scrambled: Parametric t-test | MEG
 - |Faces-Scrambled|=0: Parametric Chi2 test | EEG
 - log(|Faces-Scrambled|)=0: Parametric Chi2 test | ME
 - |Faces|=Scrambled: Parametric t-test | MEG

Report: C:\Users\francois\brainstorm\reports\report_TutorialScript_130125_1735.mat

Start: 25-Jan-2013 17:25:24 Elapsed: 9m 56s

0 errors and 3 warnings

Warning	Message	Time	
warning	[No input]	Errors detected in the events of the AUX file (markers at the beginning of a trial): Removed 1 x "left": 82.500 Removed 1 x "right": 276.000	25-Jan-2013 17:26:36
warning	Subject01@[rawsubj001_somatosensory_20111109_...]	Cannot overwrite native files.	25-Jan-2013 17:33:29
info	Subject01@[rawsubj001_somatosensory_20111109_...]	EEG058: 30 events detected in 2 categories	25-Jan-2013 17:33:31

Initial files

[No input]

Intermediate files

- Subject01@[rawsubj001_somatosensory_20111109_01_A
- Subject01@[rawsubj001_somatosensory_20111109_01_A
- Subject01/left/data_average_130125_1734.mat
- Subject01/left/data_left_trial001.mat [deleted]
- Subject01/left/data_left_trial001_bl.mat [deleted]
- Subject01/left/data_left_trial001_bl_timeoffset.mat
- Subject01/left/data_left_trial002.mat [deleted]
- Subject01/left/data_left_trial002_bl.mat [deleted]
- Subject01/left/data_left_trial002_bl_timeoffset.mat
- Subject01/left/data_left_trial003.mat [deleted]
- Subject01/left/data_left_trial003_bl.mat [deleted]
- Subject01/left/data_left_trial003_bl_timeoffset.mat

Snapshots

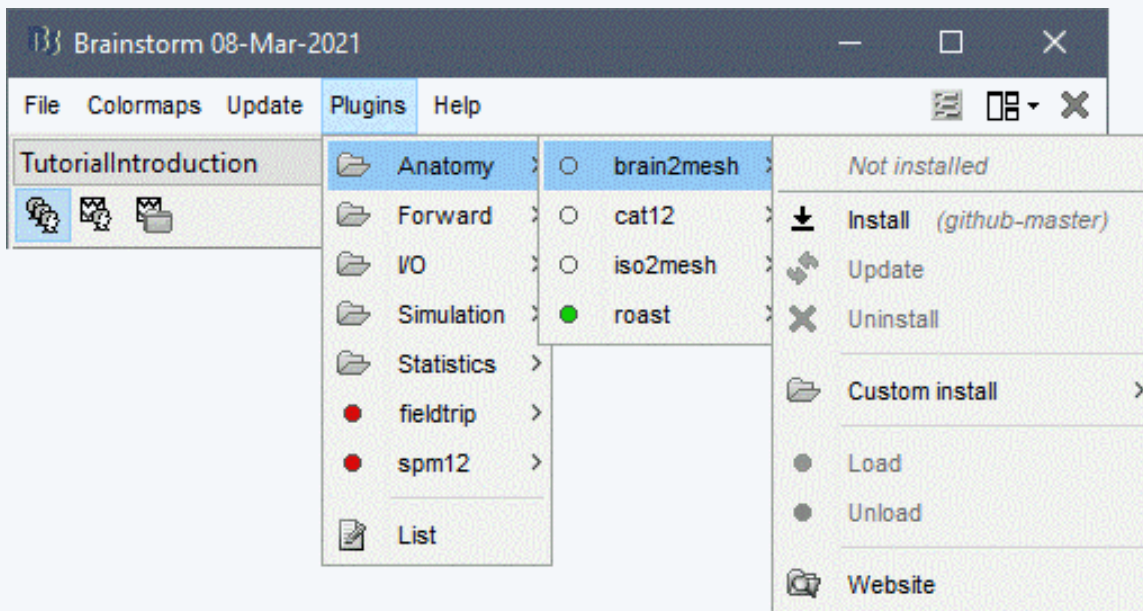
- Subject01/right/data_average_130125_1254.mat
- Subject01/left/data_average_130125_1254.mat
- Subject01/right/data_average_130125_1254.mat

The snapshots section displays three brain surface plots and two time-frequency plots. The brain surface plots show a 3D model of a head with a green mesh overlay. The time-frequency plots show Amplitude (M) vs Time (s) for GFP (Green) and other components.

Add your code to Brainstorm

- Direct manipulation of the files in Matlab
- Use the menu “Run Matlab command”
- Write a process:
 - Well documented API
 - Lots of example (230 functions written as plugins)
- Examples of recent external contributions:
 - MVPA decoding (Oliva, MIT)
 - Microstate segmentation (Cacioppo, UChicago)
 - Eyetracker/EEG synchronization (Uni Freiburg)

Plugin manager



Generic:
SPM12, FieldTrip

Anatomy:
**CAT12, Brain2Mesh,
Iso2Mesh, ROAST**

Forward modeling:
OpenMEEG, DUNEuro

Simulation:
SimMEEG

Statistics:
LibSVM

fNIRS:
NIRSTORM

I/O:
**Philips-EGI EEG
Blackrock NeuroPort
AD Instruments SDK
Neurodata Without Borders
Tucker-Davis Technologies**

User community

- 32,000 users registered on the website



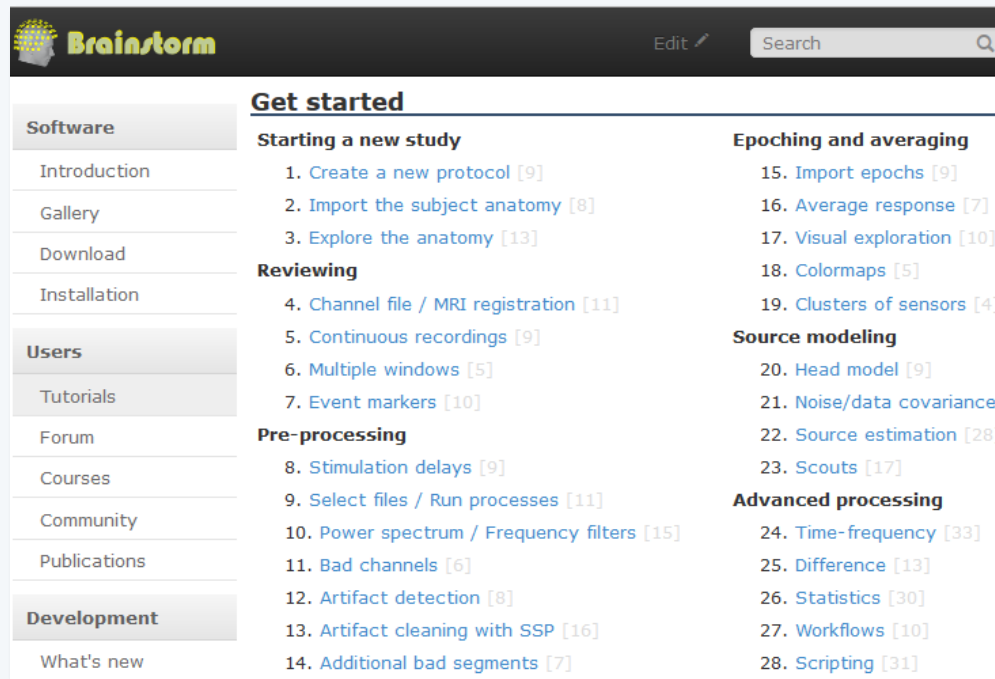
Find users next to you

Location:

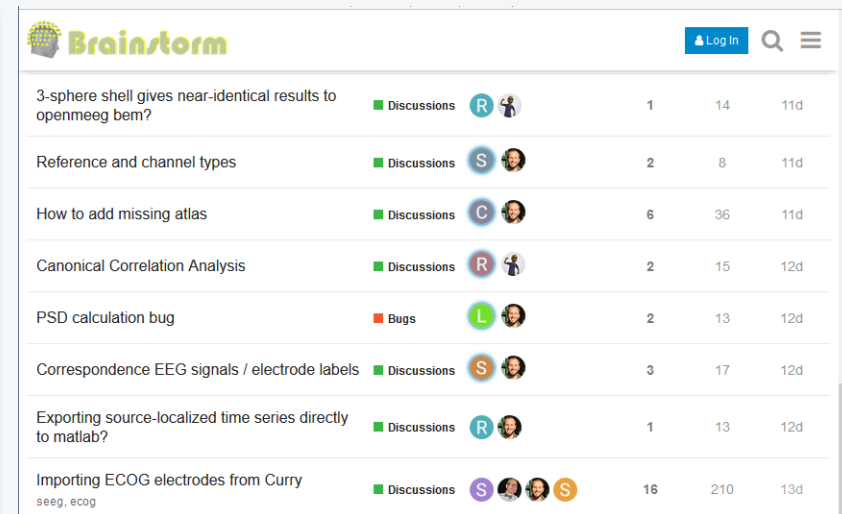
josiannebertrand	UQAM, Montreal	EEG	post-doc	2013
timothynest	Montreal, McGill	MEG, fNIRS	research	2013
Clara Moreau	Montreal	MEG	stagiaire	2013

User support

- Online tutorials: 30-hour self-training program
- Active user forum: 800 posts/month
- Daily updates: 1500 downloads/month



The screenshot shows the Brainstorm website's navigation menu. The top bar includes the Brainstorm logo, an 'Edit' button, and a search box. The main menu is organized into three main sections: 'Software', 'Users', and 'Development'. Under 'Software', there are links for 'Introduction', 'Gallery', 'Download', and 'Installation'. Under 'Users', there are links for 'Tutorials', 'Forum', 'Courses', 'Community', and 'Publications'. Under 'Development', there is a link for 'What's new'. A 'Get started' section is also visible, listing various topics like 'Starting a new study', 'Reviewing', 'Pre-processing', 'Epoching and averaging', 'Source modeling', and 'Advanced processing', each with a list of numbered links and their respective counts.



The screenshot shows the Brainstorm forum interface. The top bar includes the Brainstorm logo, a 'Log In' button, and a search box. The forum posts are listed in a table with columns for the post title, category, status, number of replies, number of views, and the time since the post was made. The posts include:

Post Title	Category	Status	Replies	Views	Time
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
MNI



Richard Leahy
USC

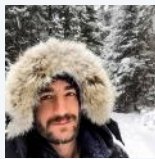


John Mosher
UT Houston



Dimitrios Pantazis
MIT

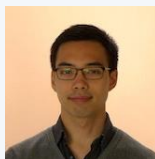
MEG @ McGill



Konstantinos Nasiotis
PhD student



Soheila Samiee
PhD student

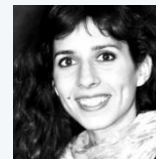


Jeremy Moreau
PhD student

Key collaborators



Elizabeth Bock
MEGIN, Chicago

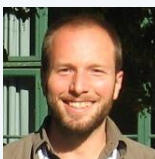


Guiomar Niso
Politécnica Madrid



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Geeks



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Software, Grenoble



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Software, MNI



Marc Lalancette
MEG manager, MNI

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Anand Joshi
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Hossein Shahabi
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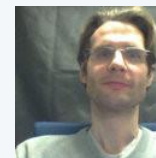


Takfarinas Medani
Research assistant

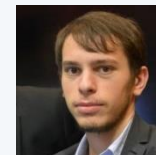
NIRSTORM



Christophe Grova
Concordia



Thomas Vincent
Montreal Heart Inst



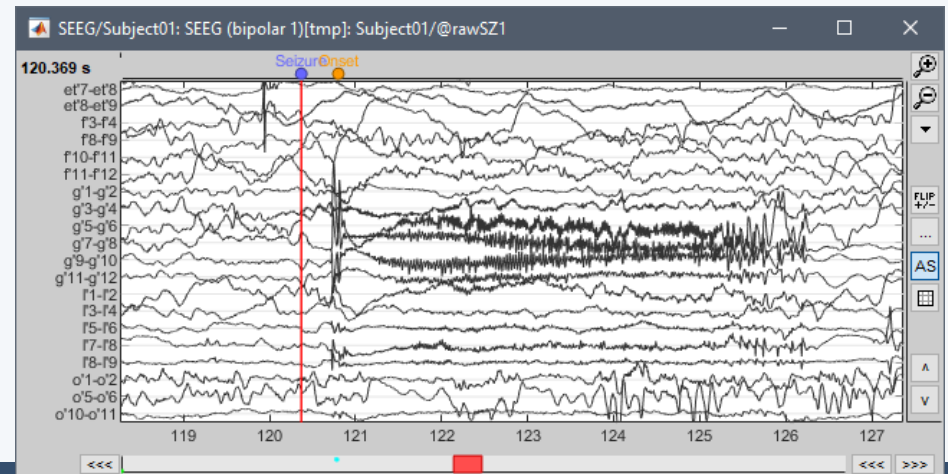
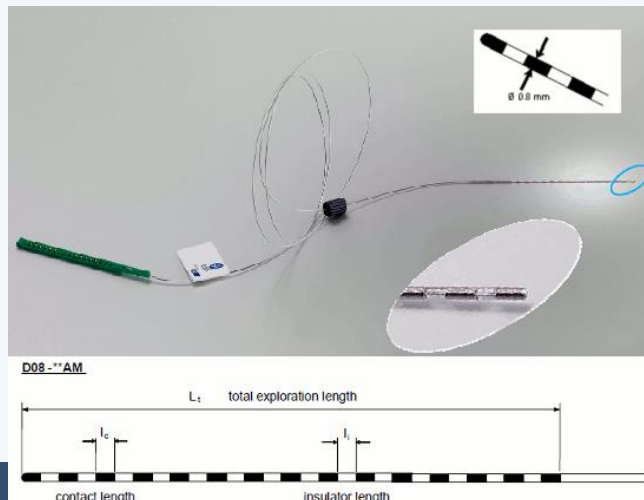
Edouard Delaire
Concordia

TODAY

Sample data

Epilepsy recordings:

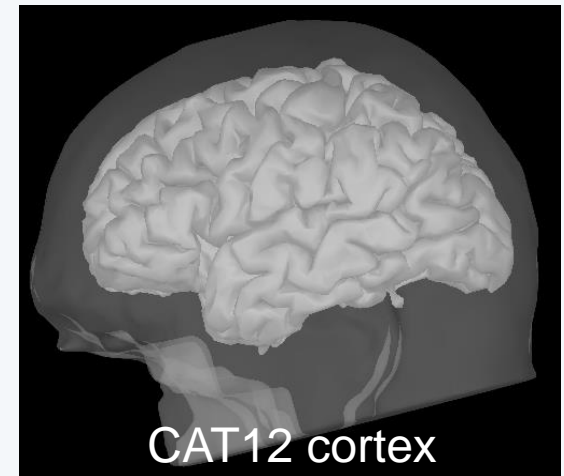
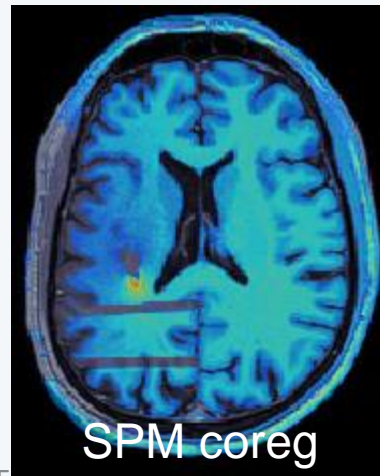
- Patient recorded at the Grenoble University Hospital
- Focal epilepsy of the left temporo-occipital junction, MRI-negative, implanted in the surrounding areas
- Depth electrodes: DIXI D08-**AM Microdeep (8-18 contacts)
- Recorded with a Micromed system at 512Hz
- 4 minutes of recordings with one generalized seizure



Sample data

Patient anatomy:

- T1 MRI pre-implantation, processed with CAT12 (r12.8)
- T1 MRI post-implantation
 - Registered on the pre-implantation image with SPM
 - Used to get 3D positions for the SEEG contacts



35

Sample data

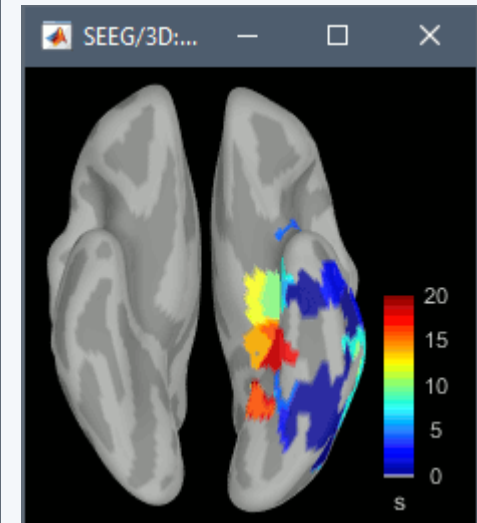
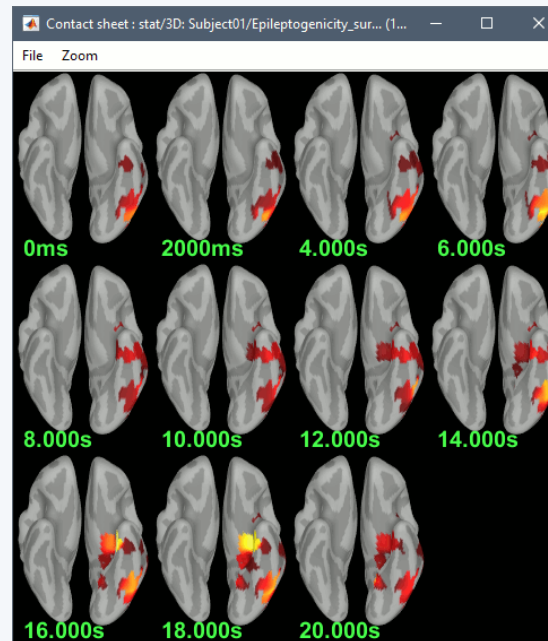
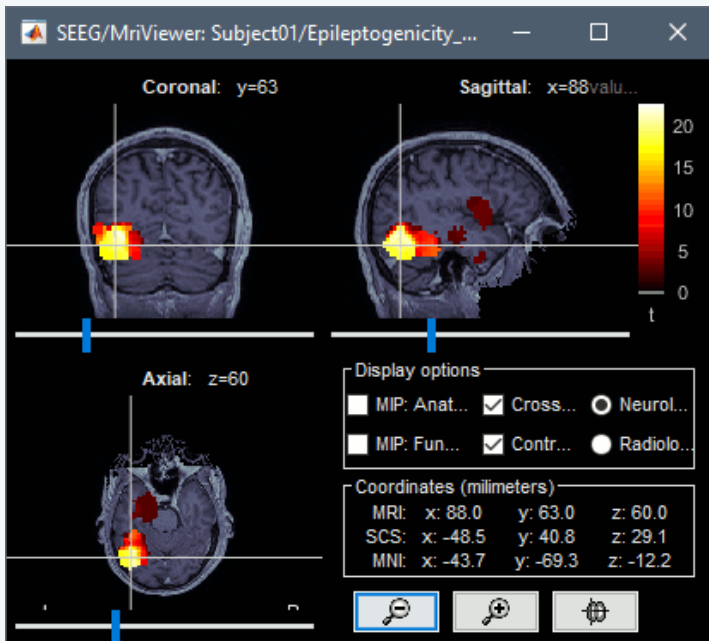
SEEG electrodes marked in the T1post:



Epileptogenicity maps

David et al., *Imaging the seizure onset zone with stereo-electroencephalography, Brain* (2011)

- Comparison of HFO power ictal vs. baseline
- Identification of the seizure onset zone
- Estimation of the seizure propagation



BIDS-iEEG specification

- **(Gorgolewski, 2016)**: The brain imaging data structure, a format for organizing and describing outputs of neuroimaging experiments
- **(Holdgraf, 2019)**: iEEG-BIDS, extending the Brain Imaging Data Structure specification to human intracranial electrophysiology
- <https://bids.neuroimaging.io/>

