Source estimation with ICA

EEGLAB

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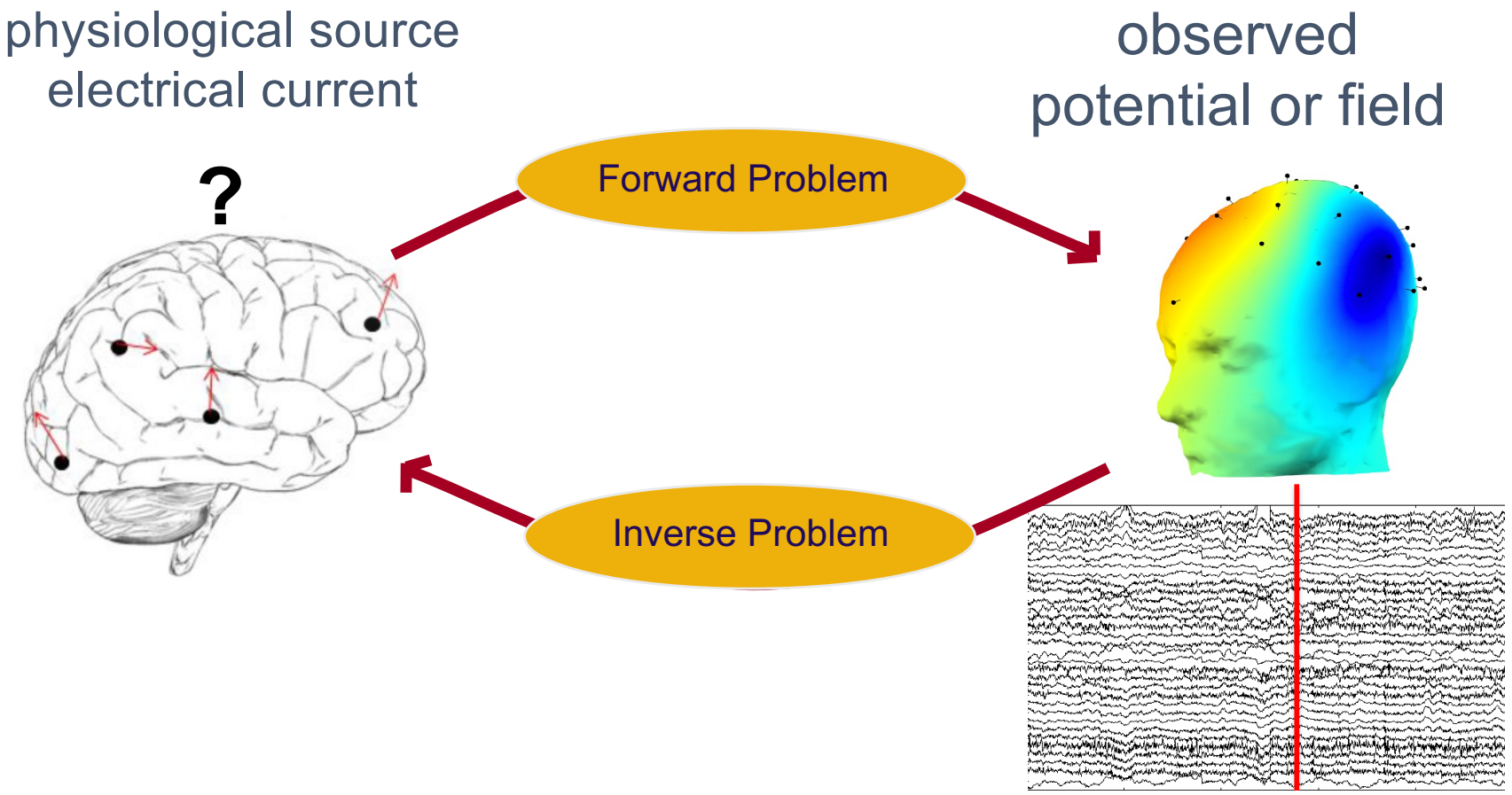
"Repetitio est mater studiorum"

("Repetition is the mother of learning")

Source modeling



Forward Head Model Problem (well posed)

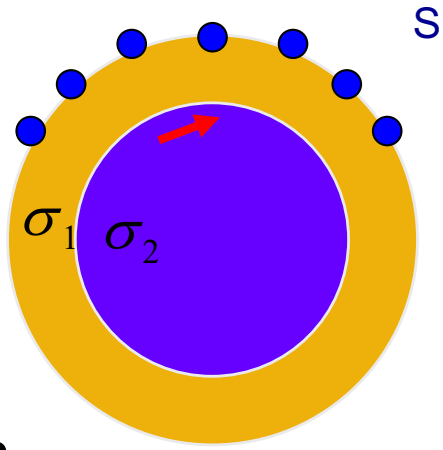
REQUIRES

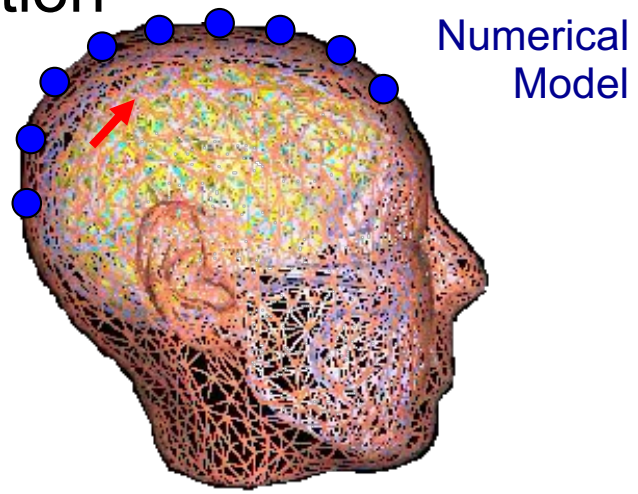
→ Head Model
- Conductivity values
- Geometry

→ Sensor Locations

→ Possible source distribution
- Magnitudes
- Locations
- Directions

→ Solver





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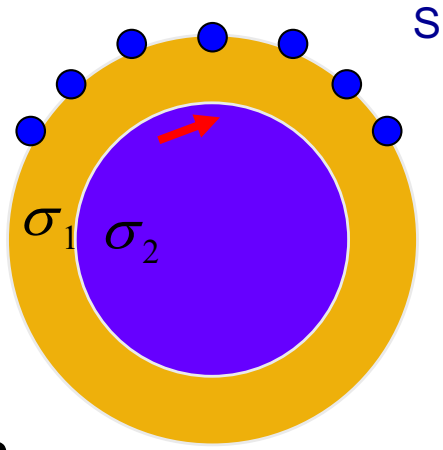
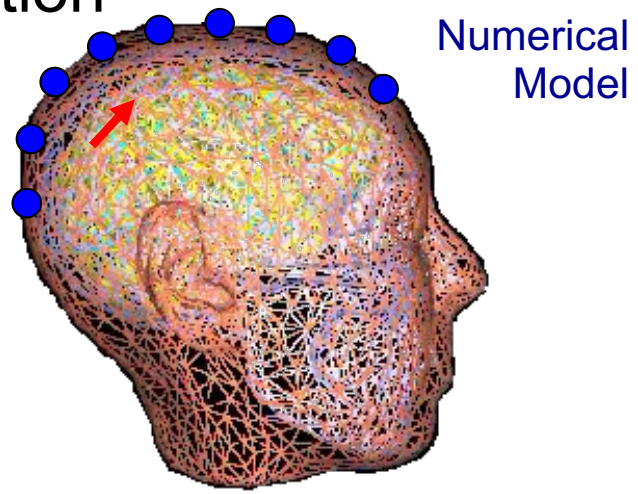
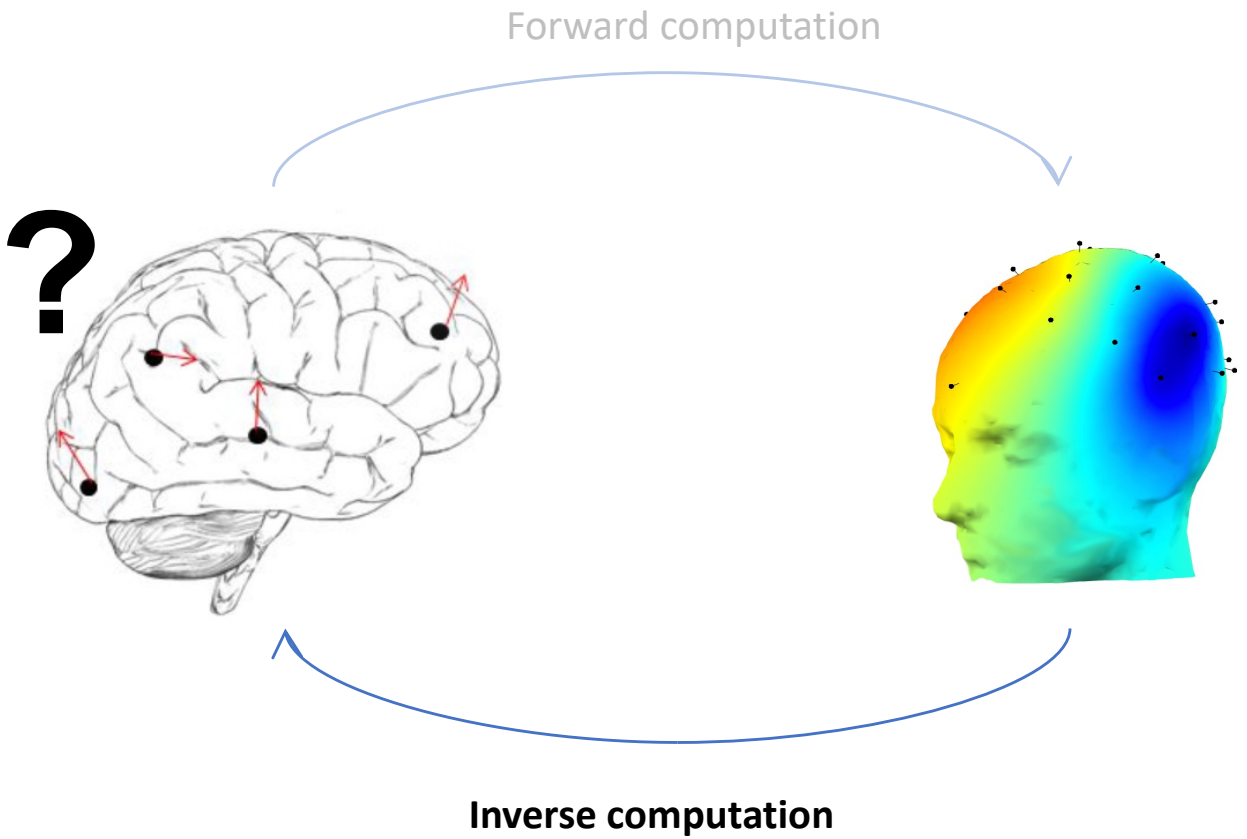




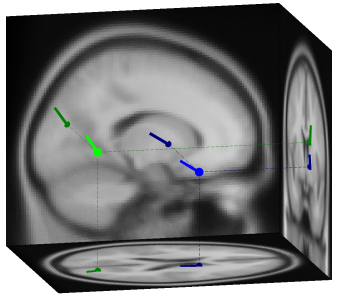
Since there is no unique solution the inverse problem is ill posed

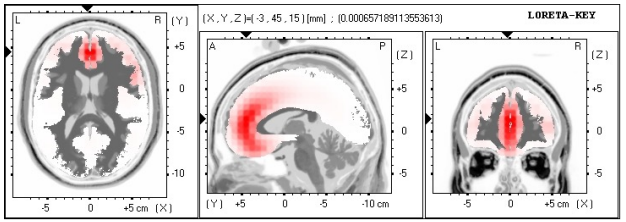


Inverse problem methods (ill posed)

Single and multiple dipole models

- Minimize error between model and measured potential/field





Distributed dipole models

- Perfect fit of model to the measured potential/field
- Minimize an additional constraint on sources
  - LORETA (assume a smooth distribution)
  - Minimum Norm (L2, minimum power at the cortex)
  - Minimum Current (L1, minimum current in the cortex)

Solving the inverse problem

- **Spatial source filtering**
  - **Scan whole brain** with single dipole and compute the filter output at every location
    - MUSIC algorithm
    - *Beamforming* (e.g., LCMV, SAM, DICS)
  - **Perform ICA decomposition** (higher-order statistics)
    - ICA gives the projections of the sources to the scalp surface, i.e., **'simple' maps**!

→ICA solves 'the first half' of the inverse problem

Plan

Part 1: ICA

- What is ICA
- ICA and EEG
- ICA Vs PCA

Part 2: Source Localization of ICA components

- Approach
- Physiological interpretation

Part 3: Practicum

Source estimation with ICA

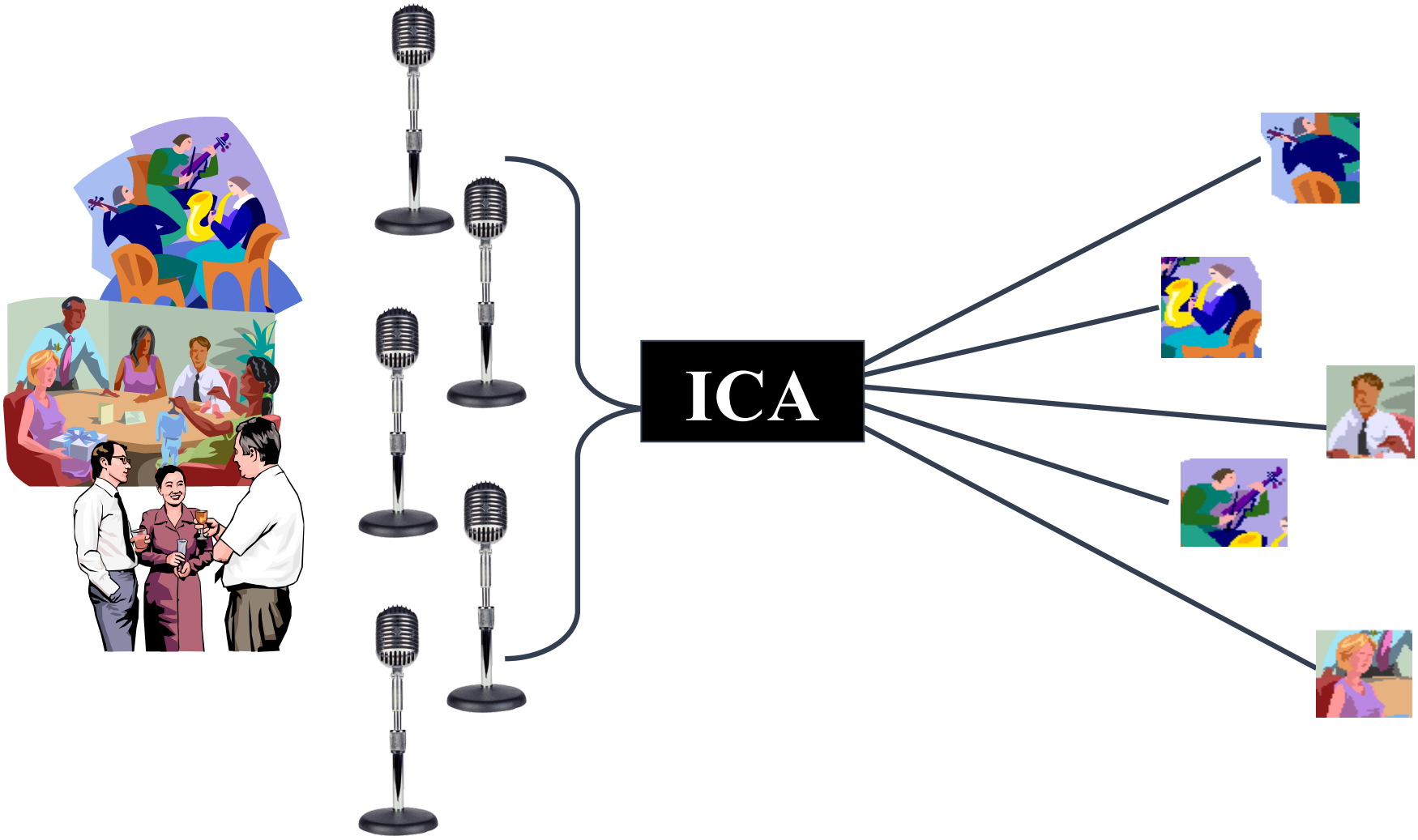
Part 1: Independent Component Analysis

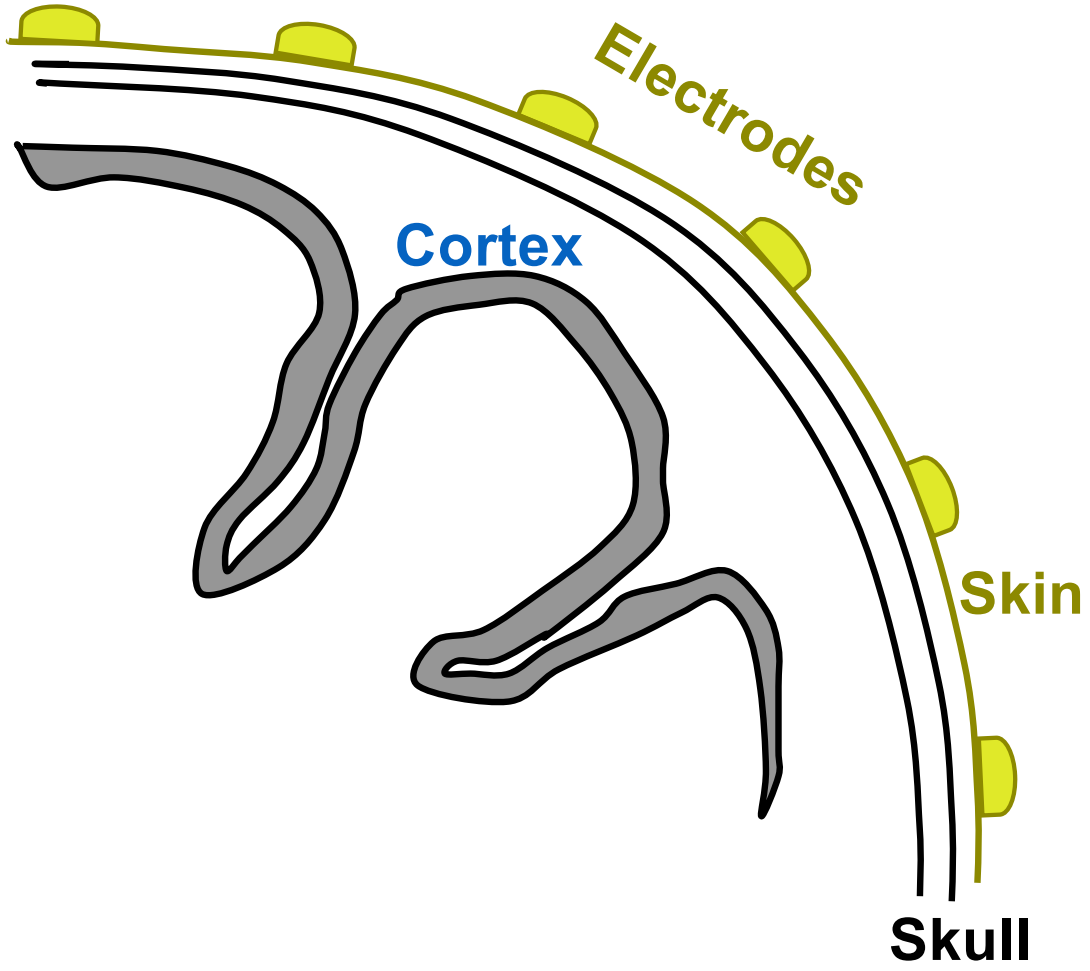
What is ICA?

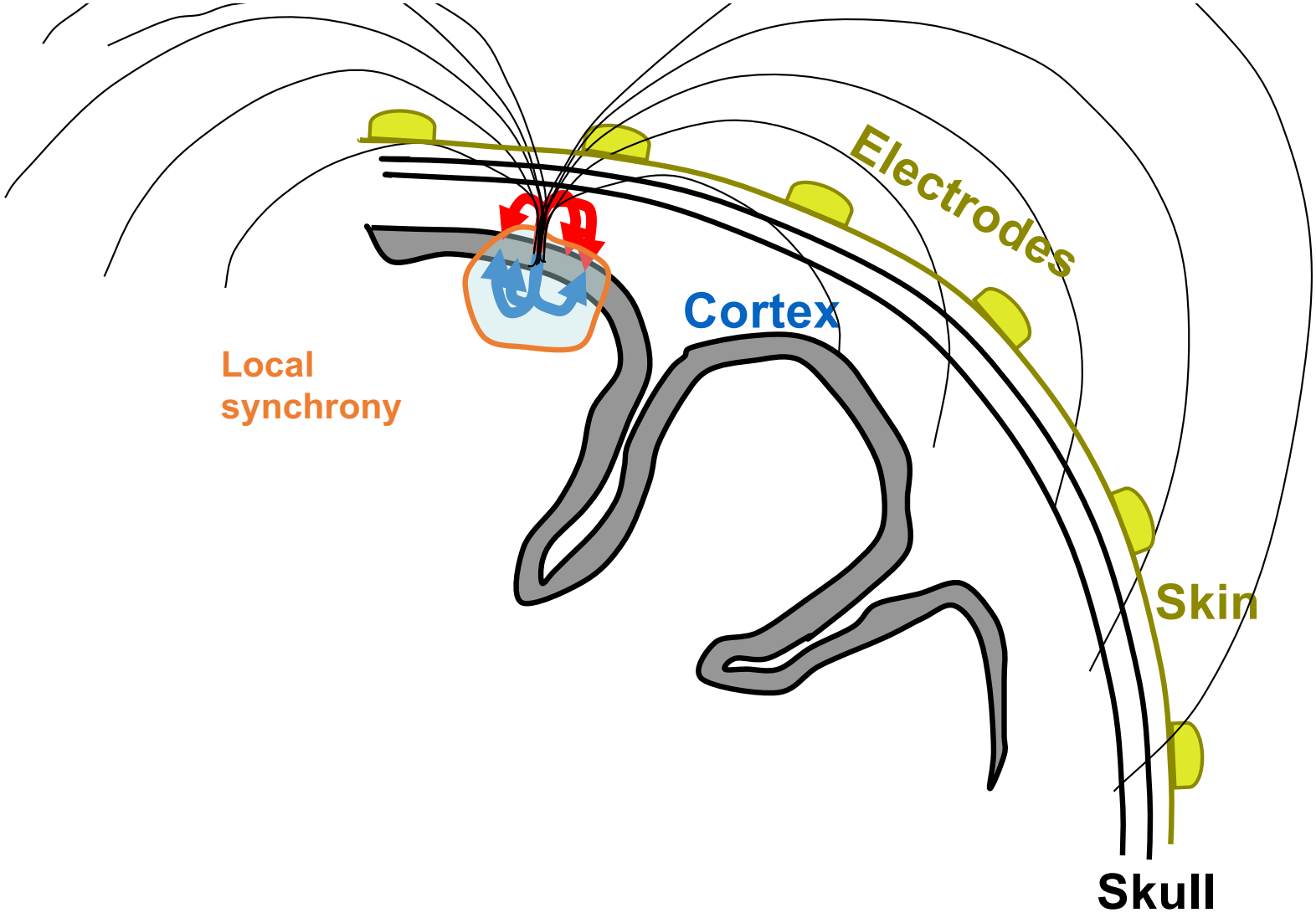
Independent Component Analysis is a signal processing method to separate independent sources linearly mixed in several sensors.

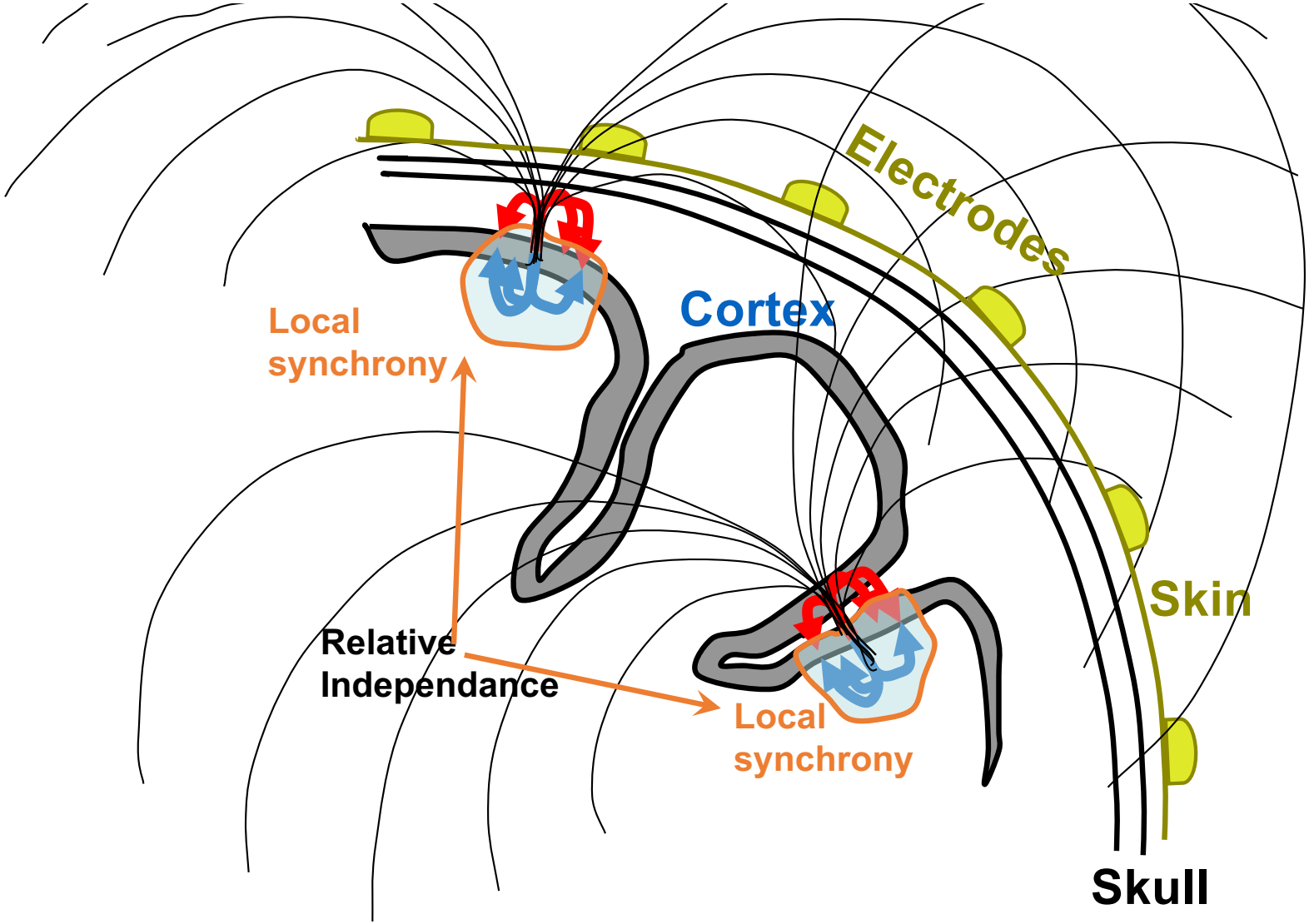
ICA for dummies
http://arnauddelorme.com/ica_for_dummies

The Cocktail Party Problem



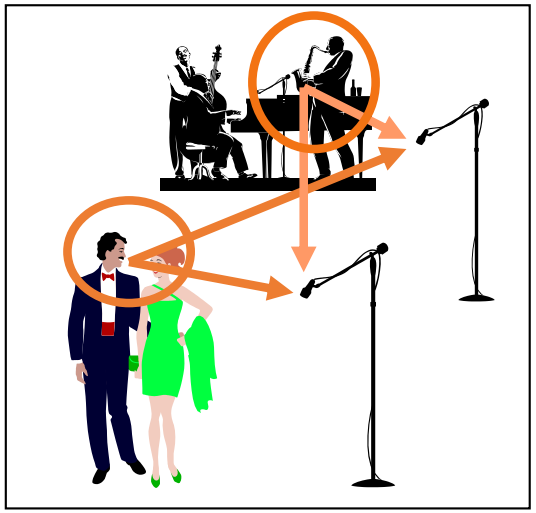

Electrodes
Cortex
Skin
Skull


Electrodes
Cortex
Local
synchrony
Skin
Skull

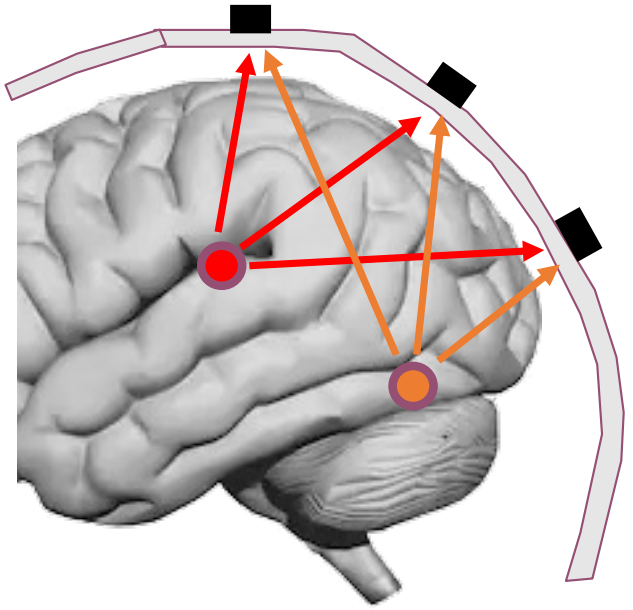

Electrodes
Cortex
Local
synchrony
Relative
Independance
Local
synchrony
Skin
Skull

Independent Component Analysis

Cocktail Party



Mixture of Brain source activity



Independent Component Analysis

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

$$U = WX$$

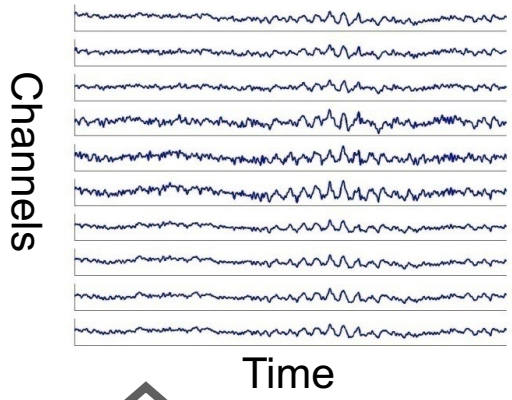
X is the data (channels x time)
U are the ICA source activities (component x time)
W is the ICA unmixing matrix (components x channels)

Independent Component Analysis

x = scalp EEG

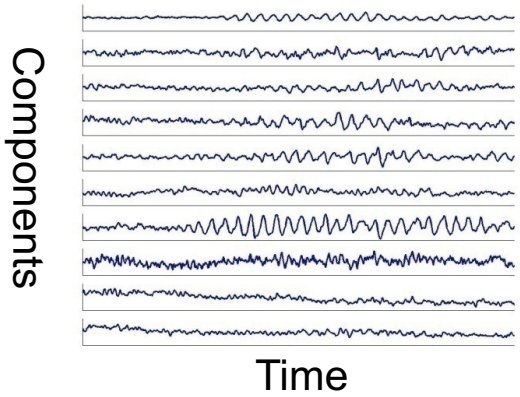
W = unmixing matrix

u = sources



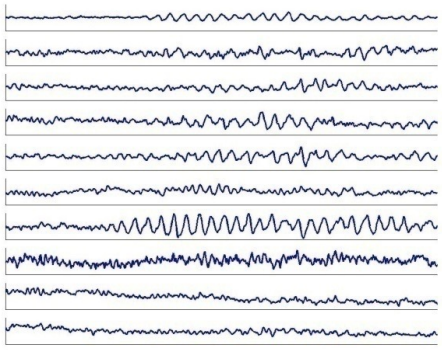
W*x = u

ICA



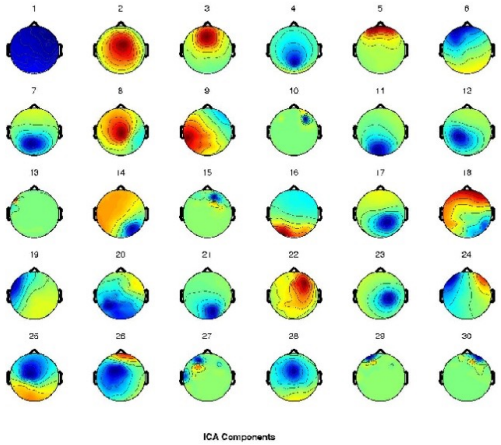
x = W^{-1}*u

u = sources



W^{-1} (scalp projections)

*



Review: ICA in Plain English

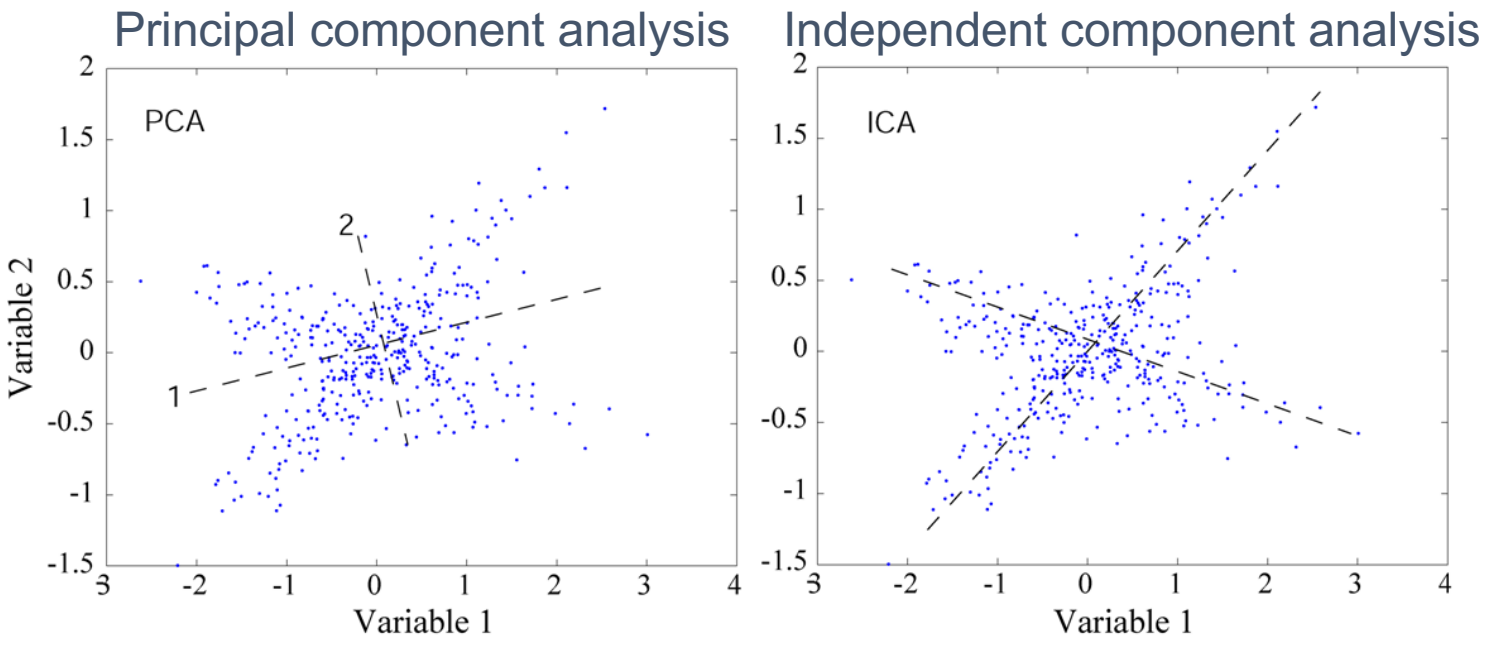
Source activation = unmixing * Channel data

Channel data = mixing (topo) * Source activation

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

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

ICA and PCA

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



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

Historical Remarks

ICA algorithms

- Herault & Jutten (1986): Seminal paper, neural network
- Bell & Sejnowski (1995): Information Maximization
- Amari et al. (1996): Natural Gradient Learning
- Cardoso (1996): JADE

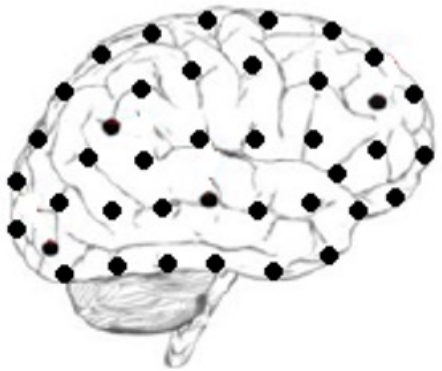
Applications of ICA to biomedical signals

- EEG/ERP analysis (Makeig, Bell, Jung & Sejnowski, 1996).
- fMRI analysis (McKeown et al. 1998)

Electrode positions

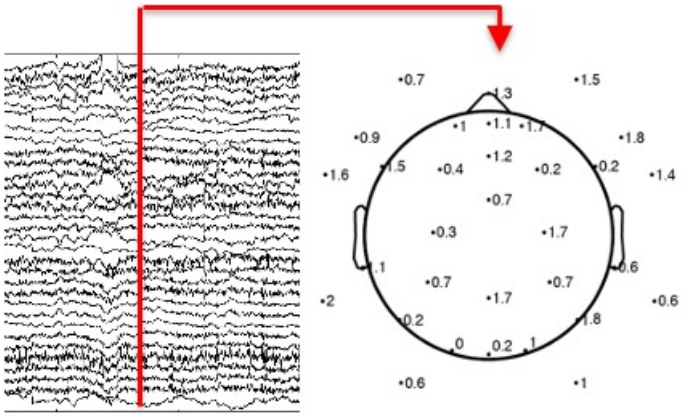
Head model
(surfaces and conductances)

Source model
(possible dipoles' location)

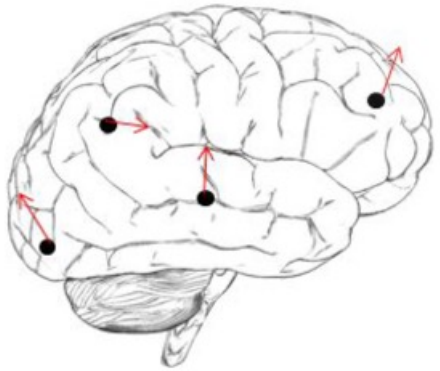


Align them all

Actual EEG data



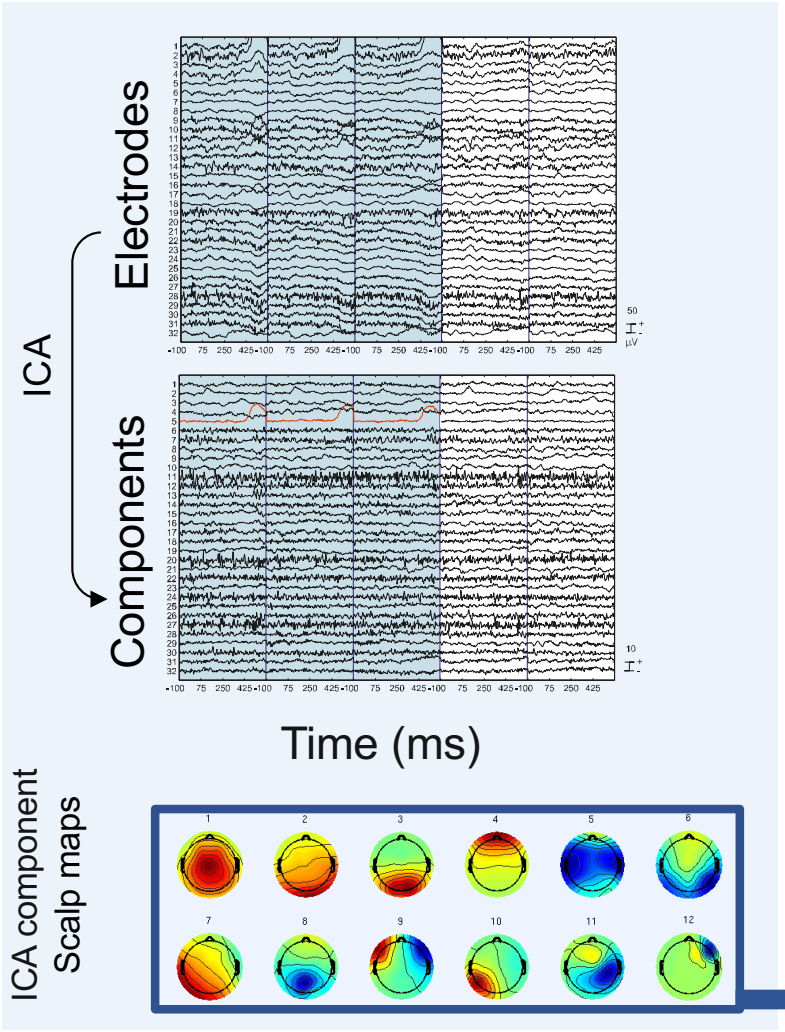
Inverse source reconstruction (eLoreta, Beamforming, …)



Source estimation with ICA

Part 2: Source Localization of ICA Components

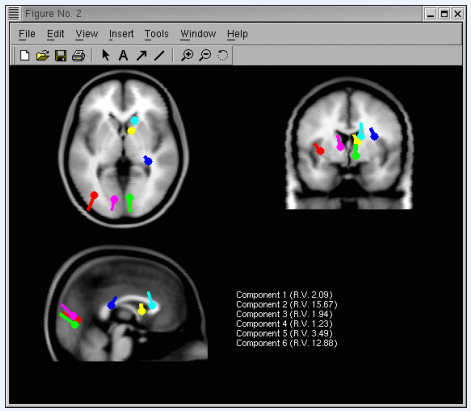
Localization

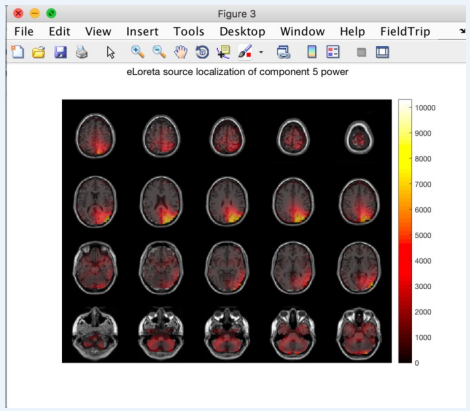


Two steps process

1. ICA takes care of unmixing of timeseries
2. Source analysis takes care of the location

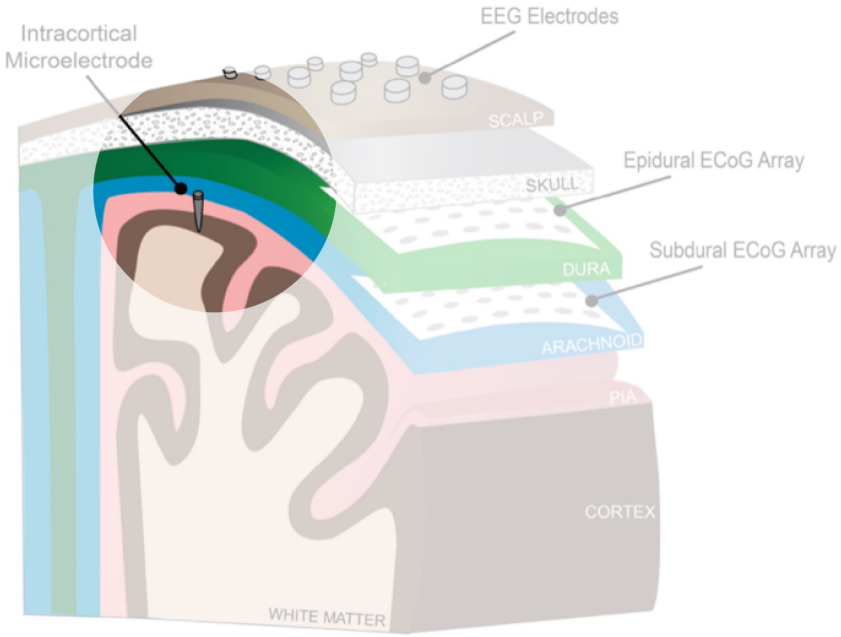
Localization



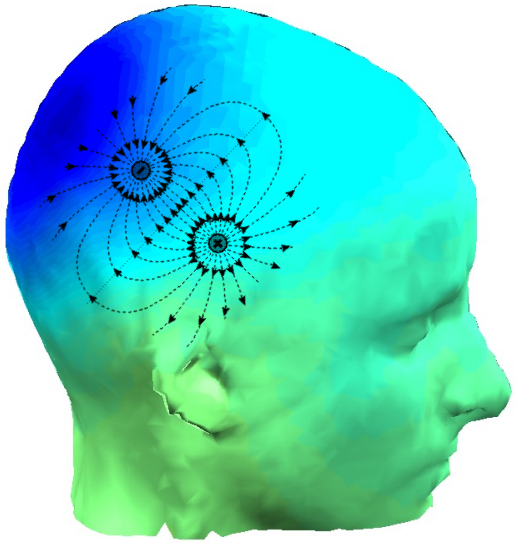


Patch of Cortex Acting as a Dipole

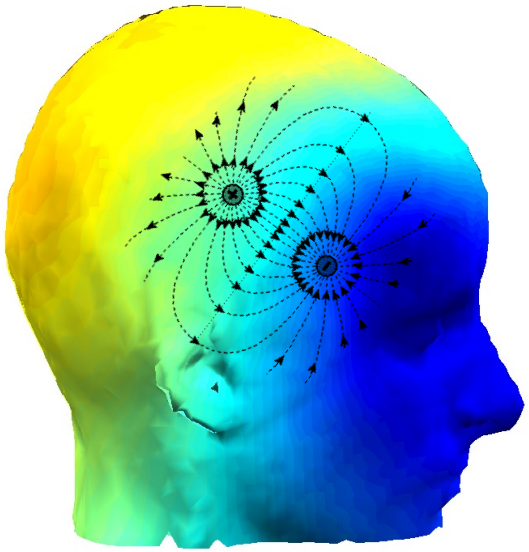
Assumption: components correspond to compact spatial patches (or bilateral patches)

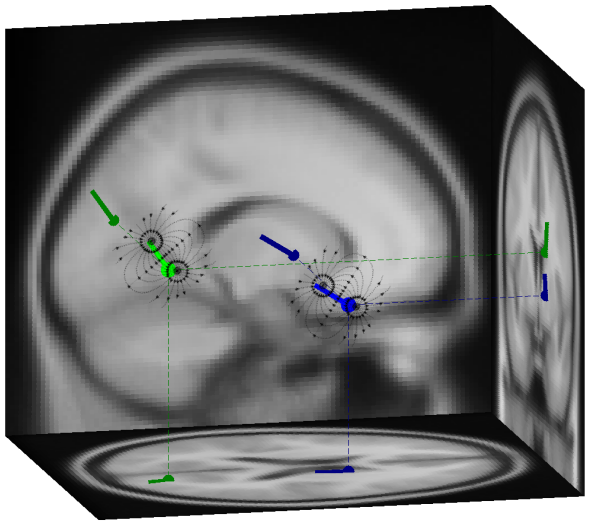


Dipolar Scalp projections



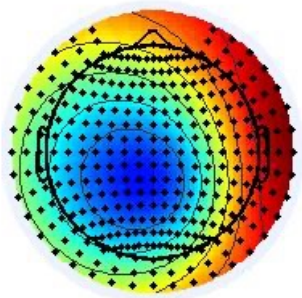
ICA creates a spatial filter for each temporally independent source



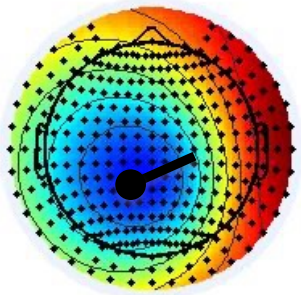


Computing Residual Variance

Actual IC map (x_i)



Dipole projection ($\tilde{x}_i$)



$$rv = \frac{\sum_i (x_i - \tilde{x}_i)^2}{\sum_i {x_i}^2}$$

Source estimation with ICA

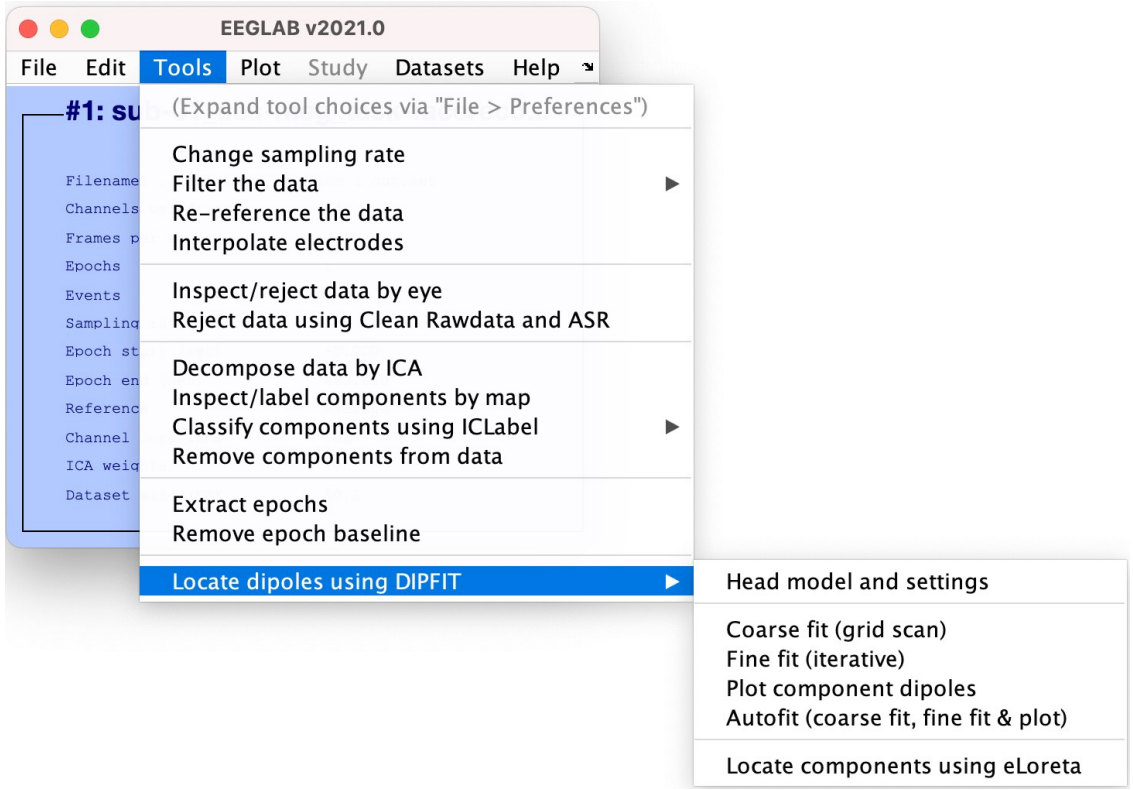
Part 3: Practicum

Co-register electrodes with model

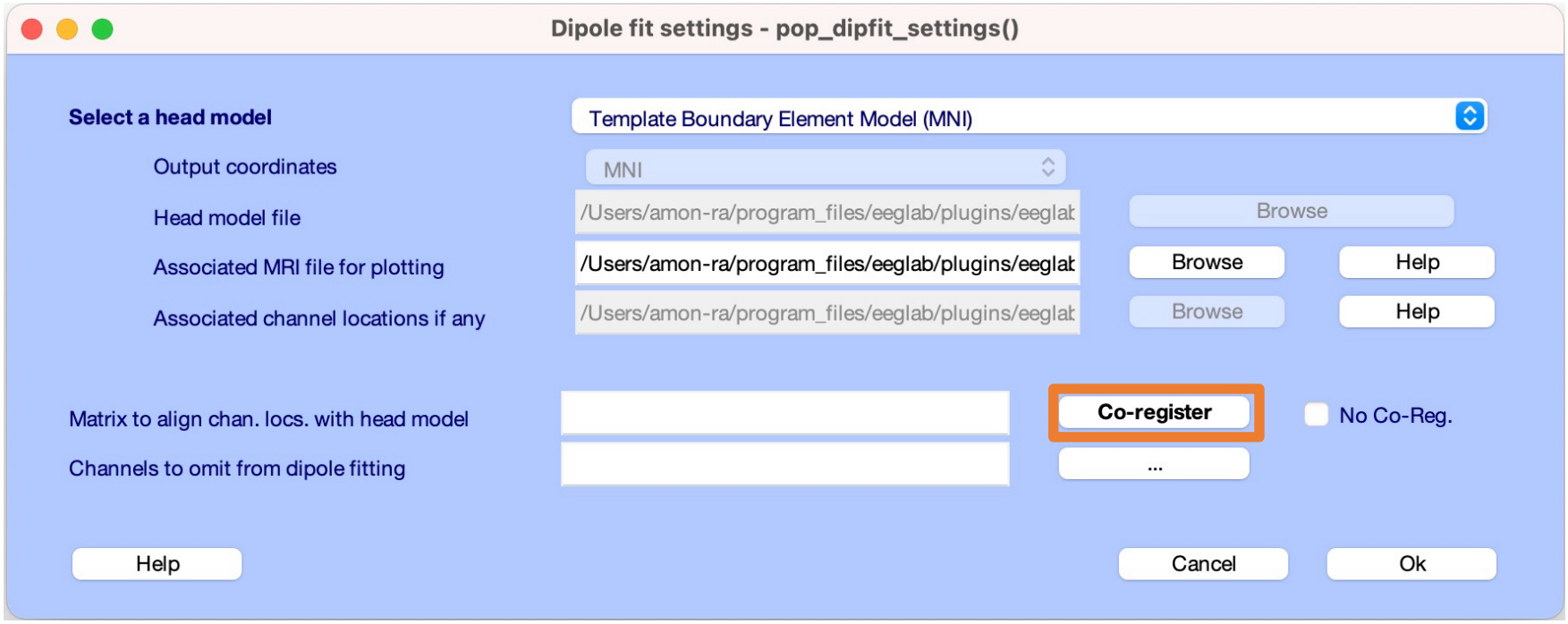
Getting ready

1. Load dataset
   `'wh_S01_run_01_preprocessing_data_session_1_out.set'`

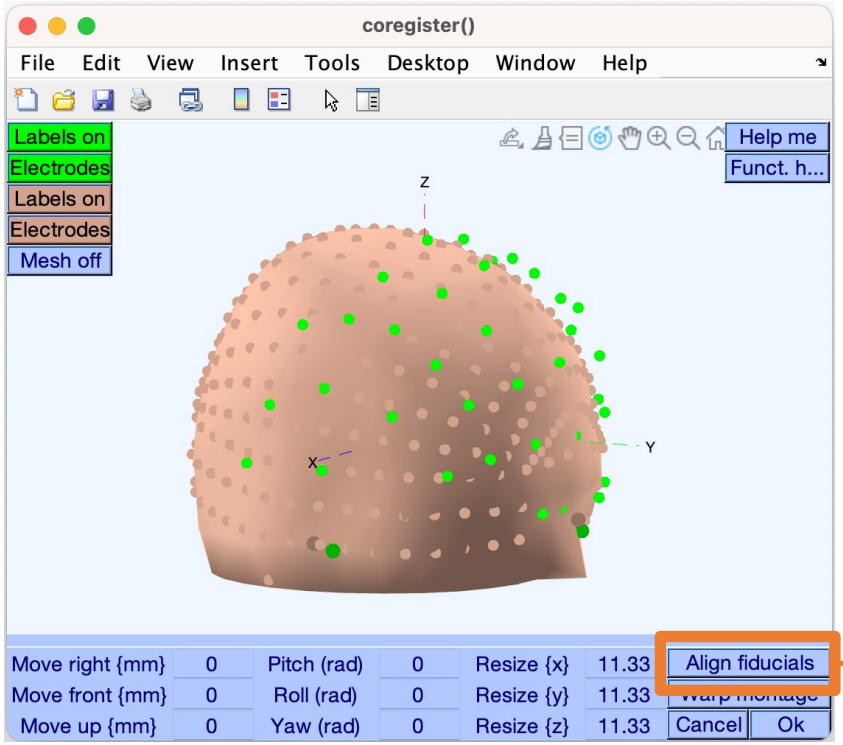
DIPFIT


EEGLAB v2021.0
File
Edit
Tools
Plot
Study
Datasets
Help
#1: su
Filename
Channels
Frames p
Epochs
Events
Samplinq
Epoch st
Epoch en
Referenc
Channel
ICA weiq
Dataset
(Expand tool choices via "File > Preferences")
Change sampling rate
Filter the data
Re-reference the data
Interpolate electrodes
Inspect/reject data by eye
Reject data using Clean Rawdata and ASR
Decompose data by ICA
Inspect/label components by map
Classify components using ICLabel
Remove components from data
Extract epochs
Remove epoch baseline
Locate dipoles using DIPFIT
Head model and settings
Coarse fit (grid scan)
Fine fit (iterative)
Plot component dipoles
Autofit (coarse fit, fine fit & plot)
Locate components using eLoreta

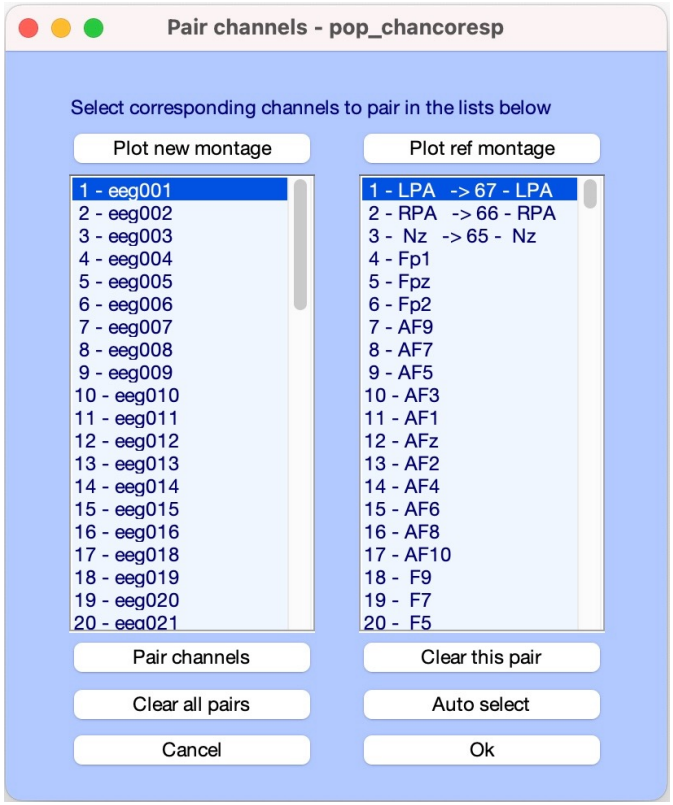
Head model and settings



Warp to standard montage

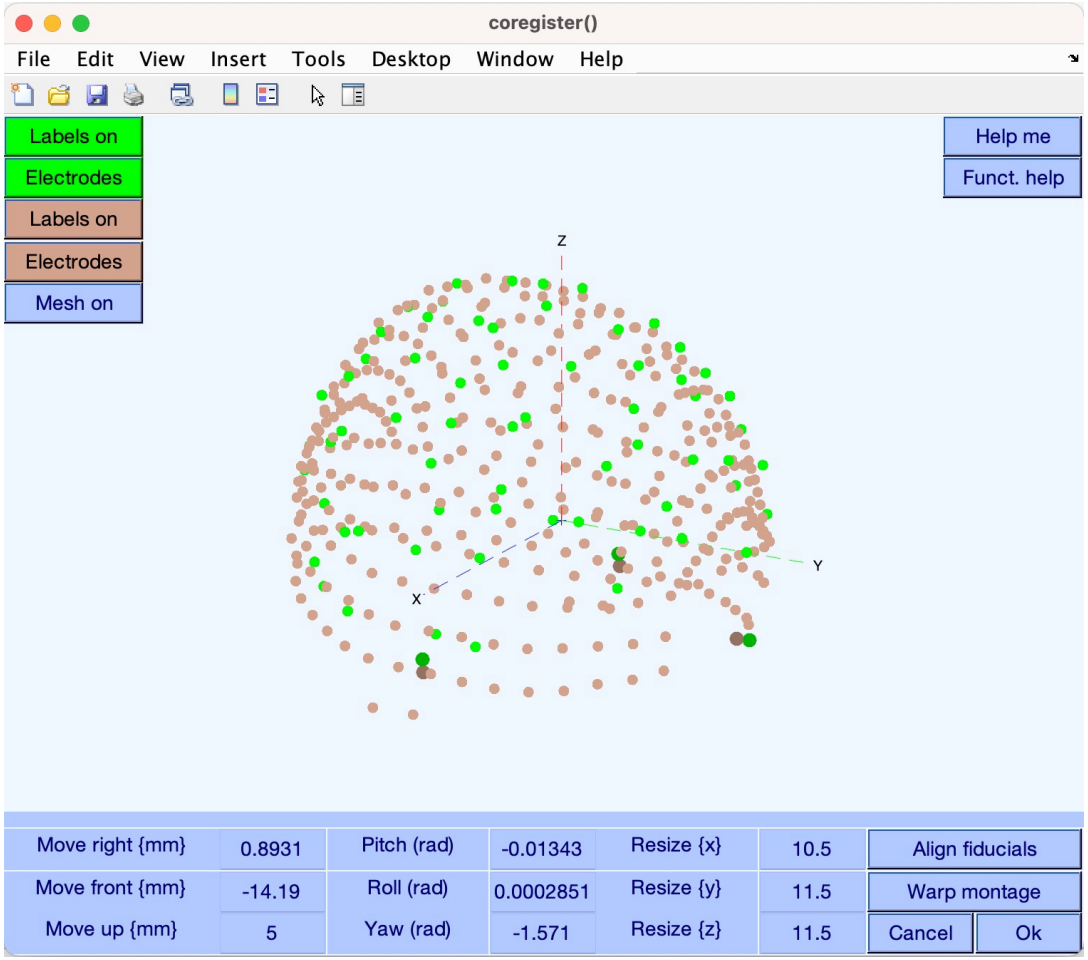


Check matching of data electrodes to the head model electrodes

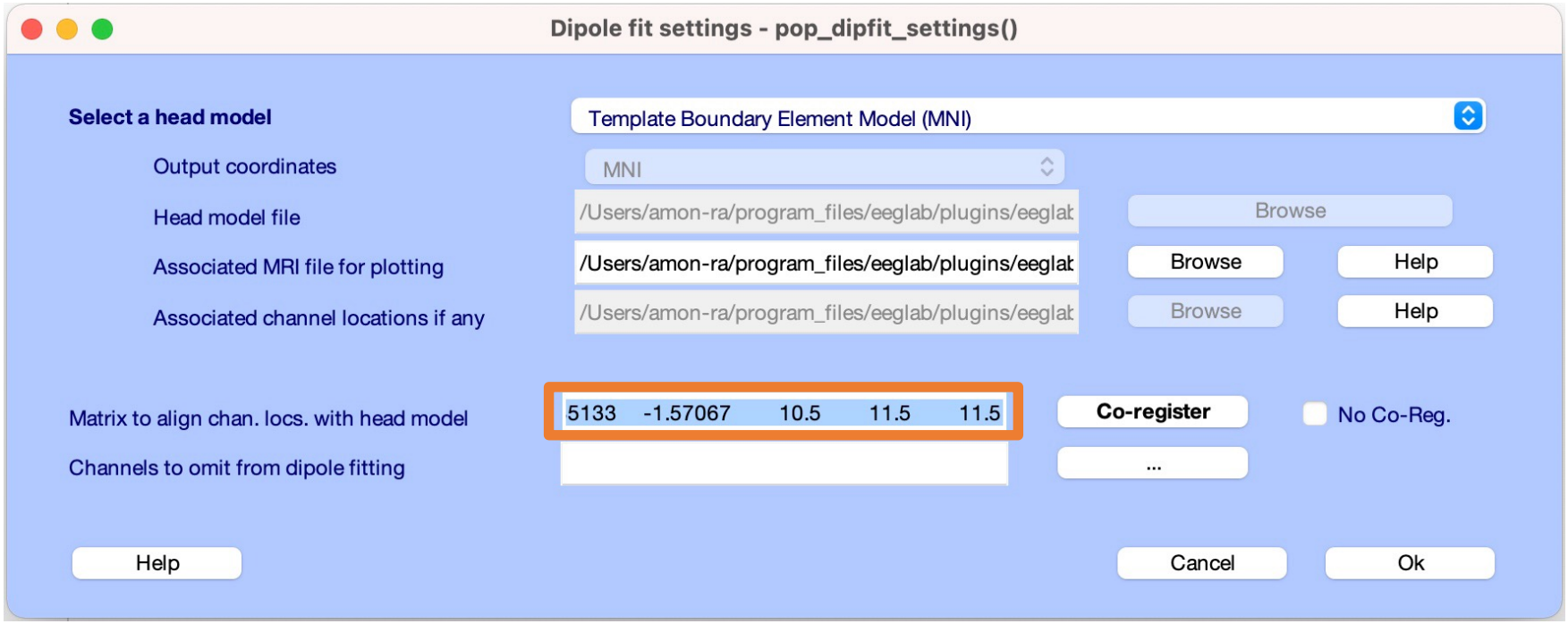


stats toolbox may be required for warping!

Check Coregistration with Model



Confirm Transformation

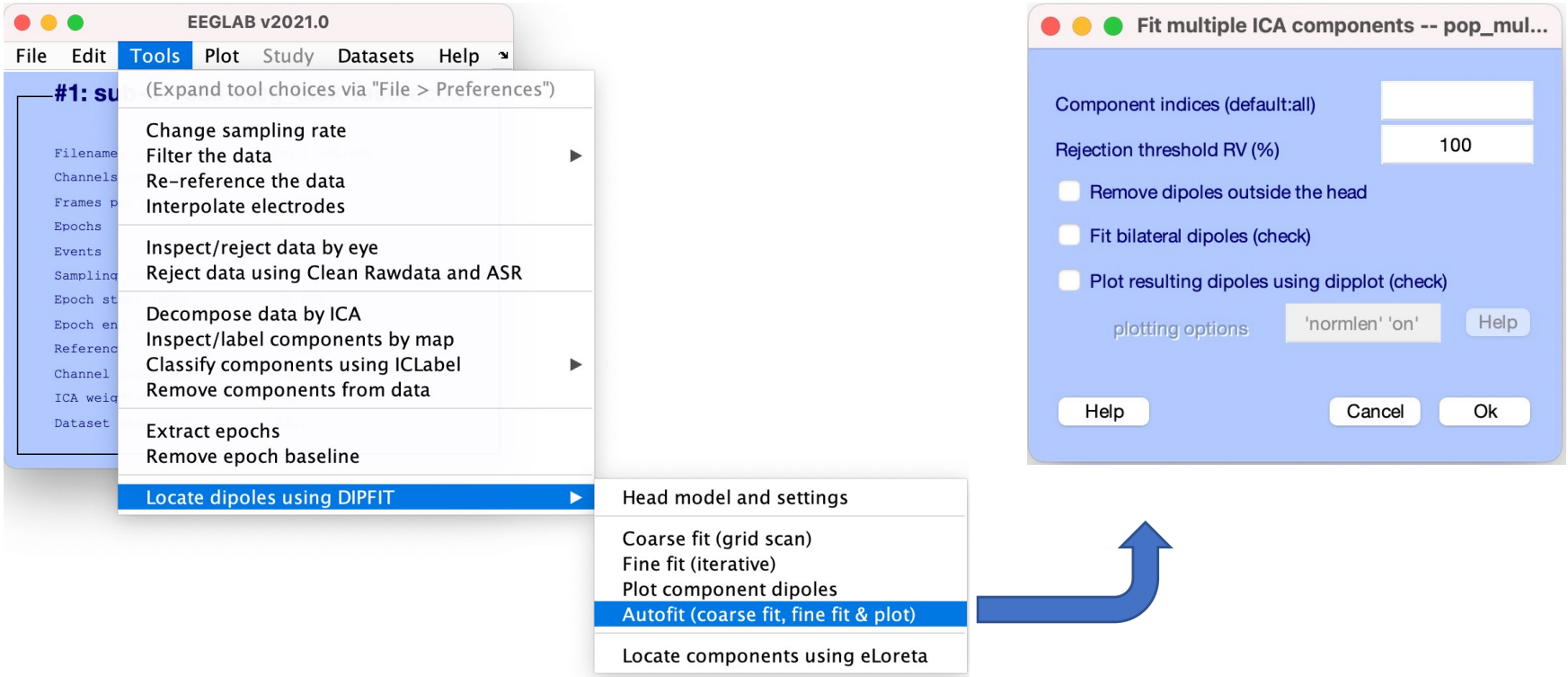


EEG.dipfit structure

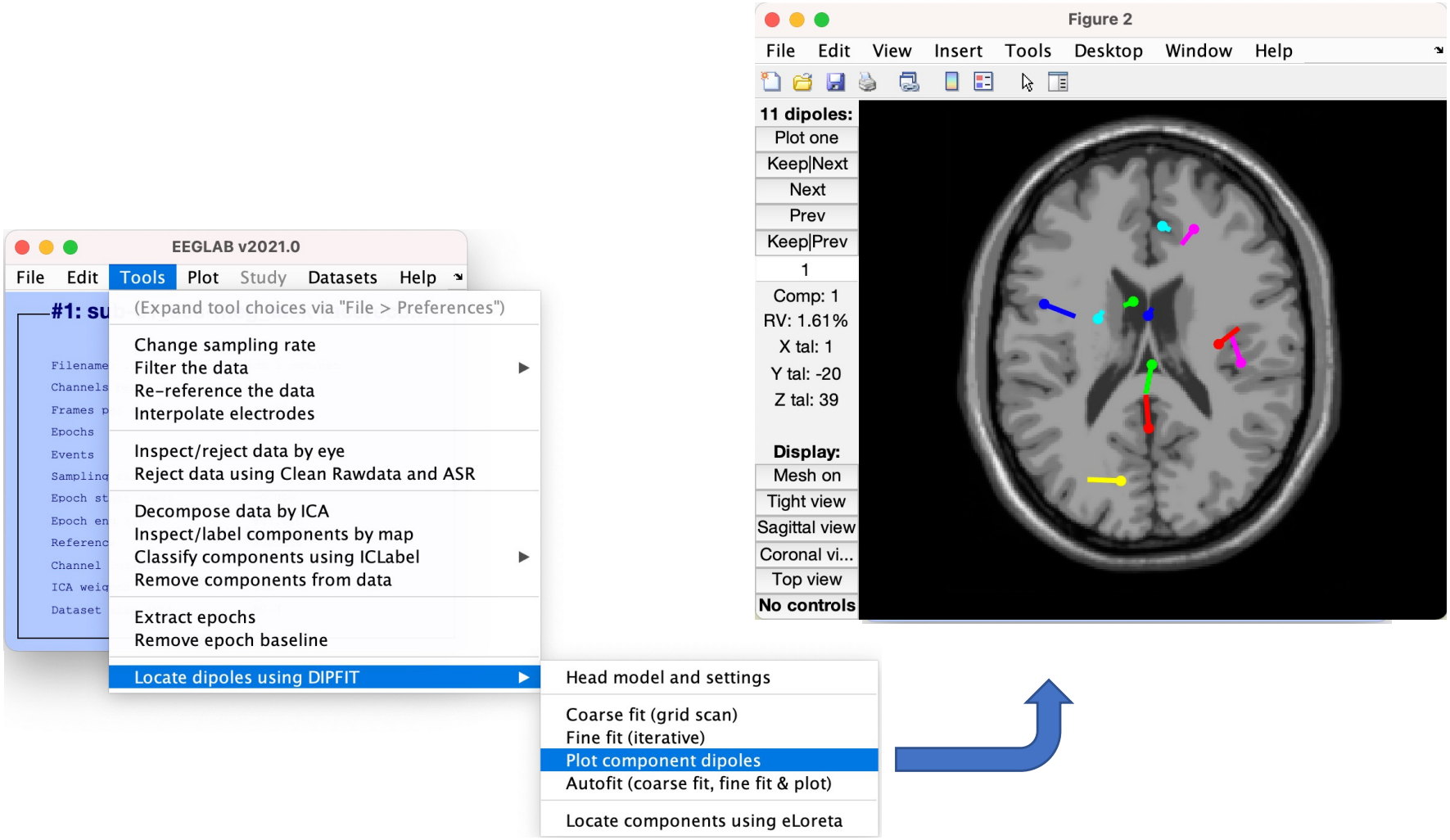
```
>>  EEG.dipfit
ans =
  struct with fields:

           hdmfile: '… eeglab/plugins/eeglab2021.0/plugins/dipfit/standard_BEM/standard_vol.mat'
           mrifile: '… eglab/plugins/eeglab2021.0/plugins/dipfit/standard_BEM/standard_mri.mat'
          chanfile: '… eeglab/plugins/eeglab2021.0/plugins/dipfit/standard_BEM/elec/standard_1005.elc'
           chansel: [1 : 11]
       coordformat: 'MNI'
    coord_transform: [0.8931 -14.1933 5 -0.0134 2.8513e-04 -1.5707 10.5000 11.5000 11.5000]
```

Autofit, plot dipoles, fine fit

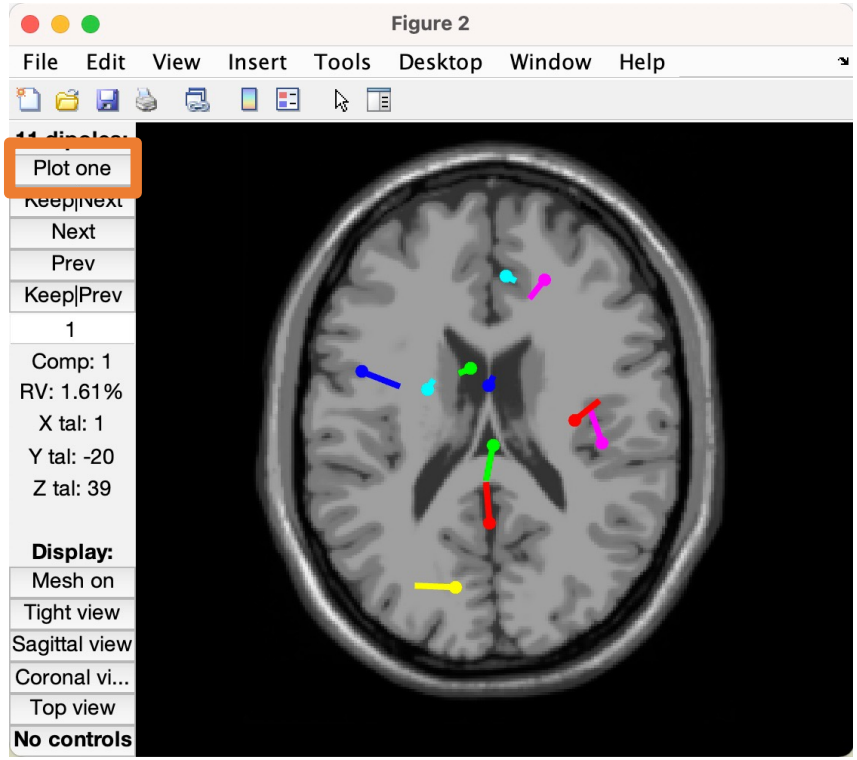
EEG.dipfit structure

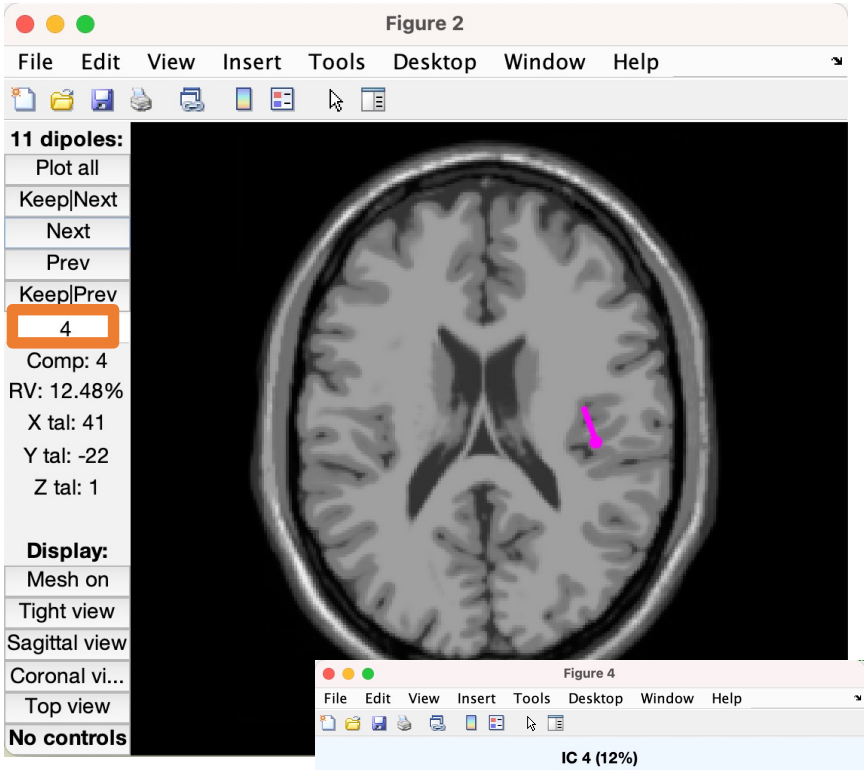


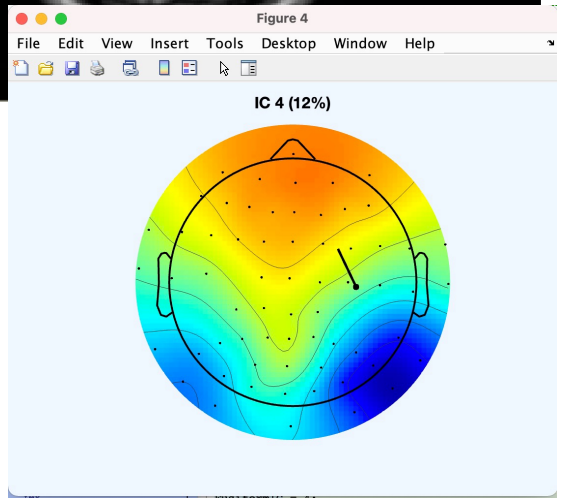
Plot Dipoles



Plot Dipoles

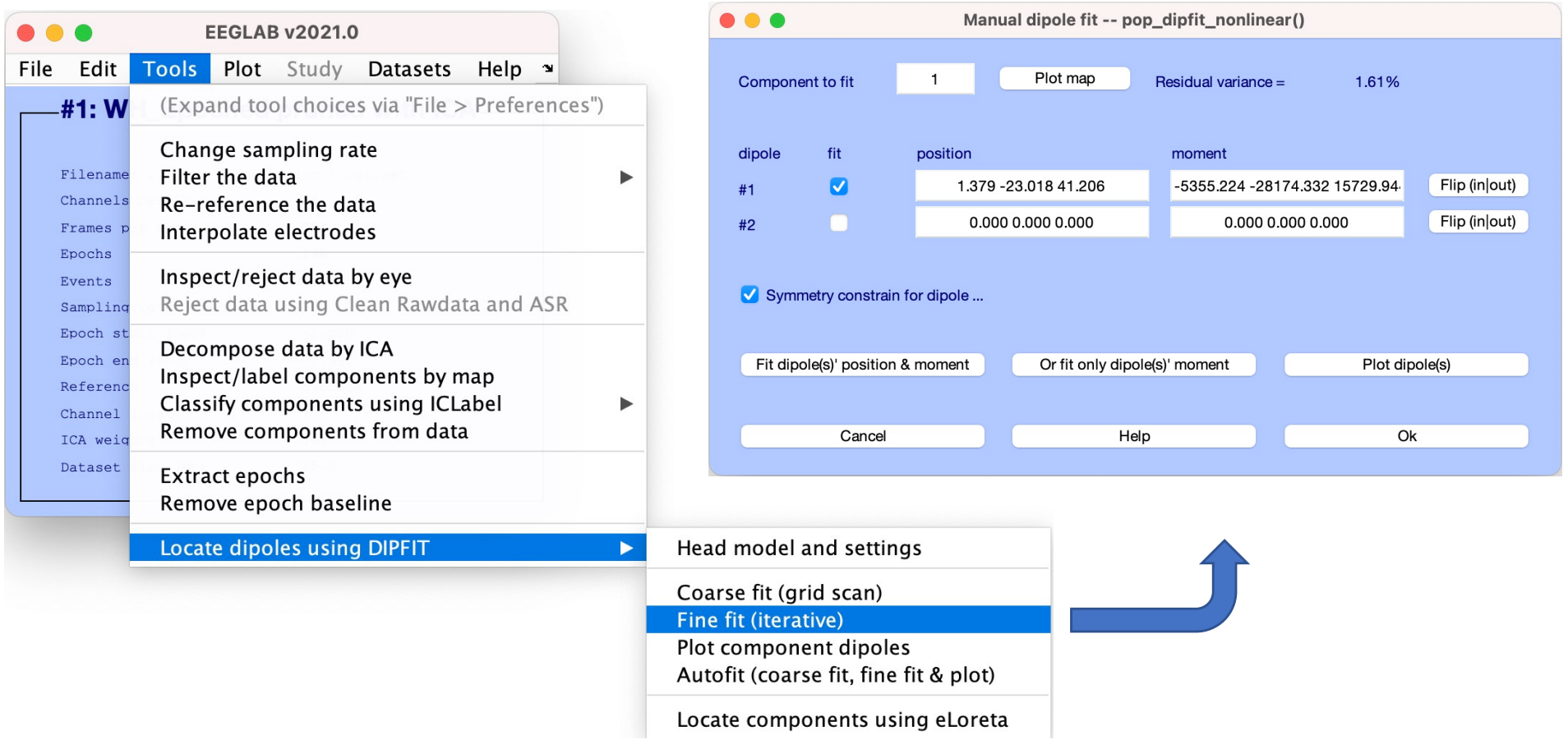




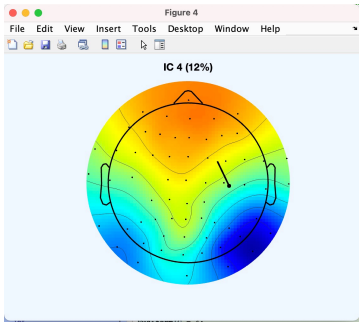


IC Map associated to dipole 4

Fine fit options in DIPFIT: Fitting two dipoles



Fine fit options in DIPFIT: Fitting two dipoles



Manual dipole fit -- pop_dipfit_nonlinear()

Component to fit 4 Plot map Residual variance = 12.48%

dipole	fit	position	moment	
#1	☑	41.322 -22.269 -0.435	-10246.555 28421.720 12903.76	Flip (in|out)
#2	☑	0.000 0.000 0.000	0.000 0.000 0.000	Flip (in|out)

☑ Symmetry constrain for dipole ...

Fit dipole(s)' position & moment | Or fit only dipole(s)' moment | Plot dipole(s)

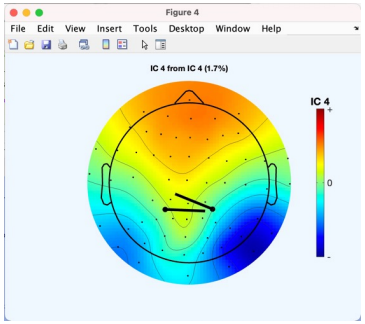
Cancel | Help | Ok

Manual dipole fit -- pop_dipfit_nonlinear()

Component to fit 4 Plot map Residual variance = 1.74%

dipole	fit	position	moment	
#1	☑	-23.592 -52.084 -14.582	60020.211 -3260.117 7635.820	Flip (in|out)
#2	☑	23.592 -52.084 -14.582	-66655.609 34418.302 -7802.43	Flip (in|out)

☑ Symmetry constrain for dipole ...



Exercise

- Load .set file using menu item *File > Load existing dataset*

‘ds000117_pruned/derivatives/meg_derivatives/sub-01/ses-meg/meg/wh_S01_run_01_preprocessing_data_session_1_out.set’

- Select BEM model using menu item

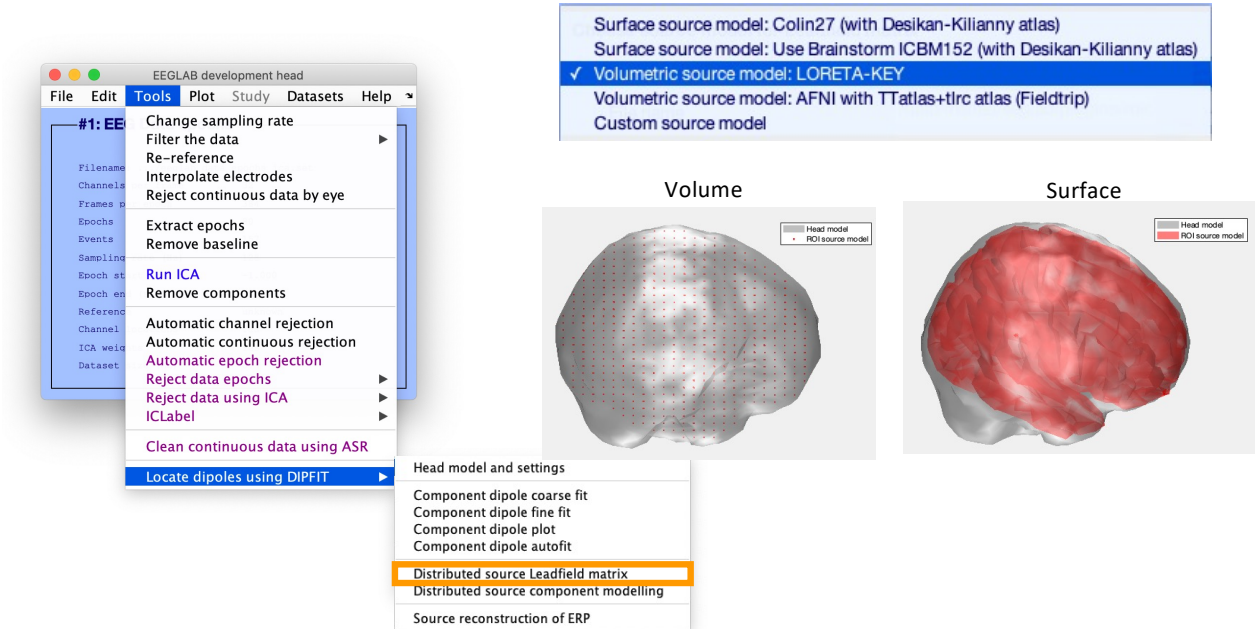
Source localization using DIPFIT > Head model and settings

- Fine fit dipole number 3 using menu item

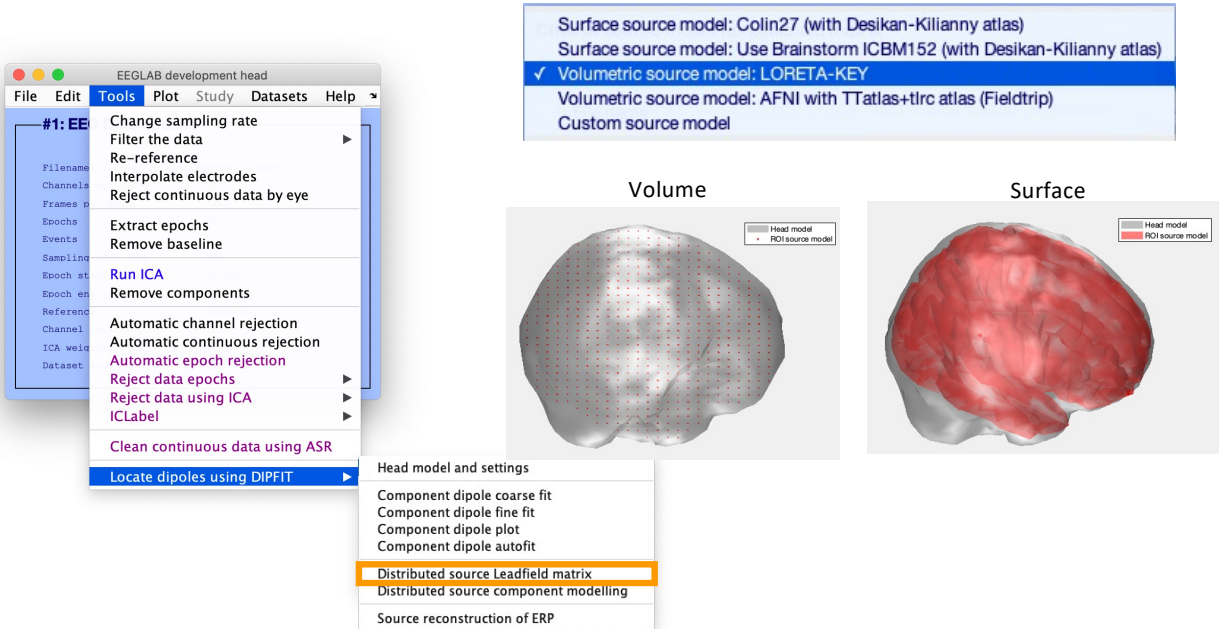
Source localization using DIPFIT > Component dipole autofit

eLORETA

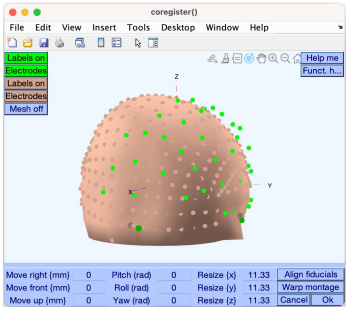
Distributed source localization in DIPFIT



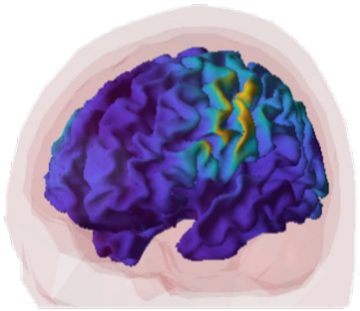
Distributed source localization in DIPFIT



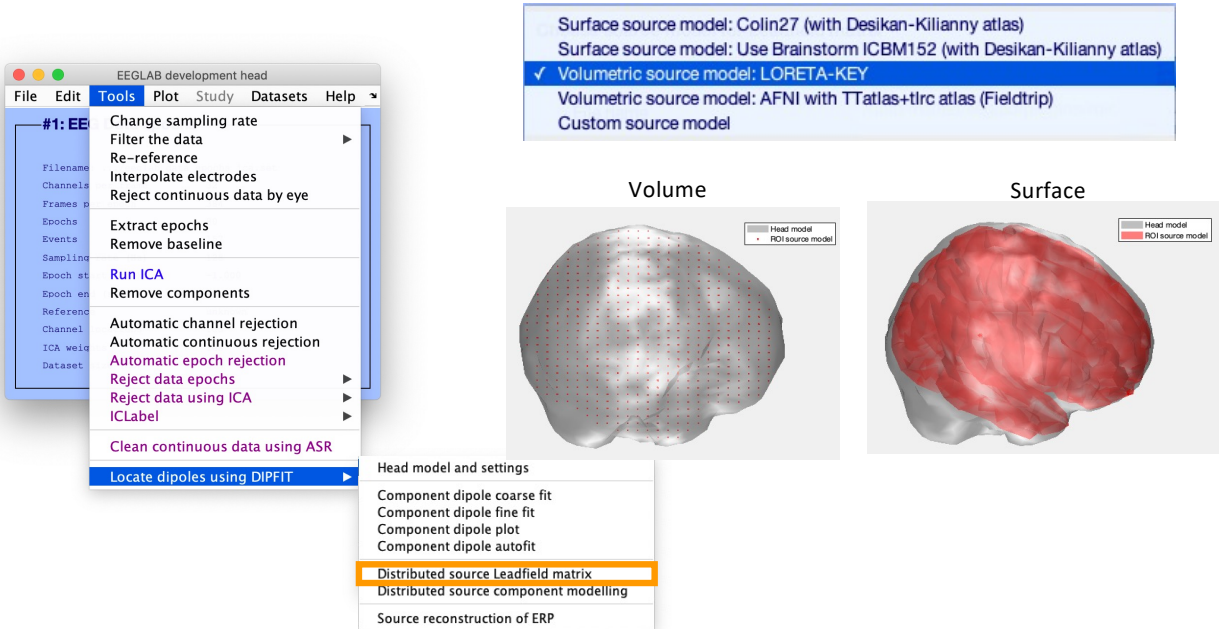
Electrode <-> Head model



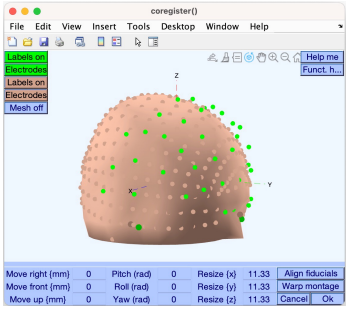
Head model <-> Source model (blue)



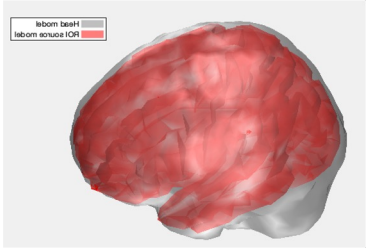
Distributed source localization in DIPFIT

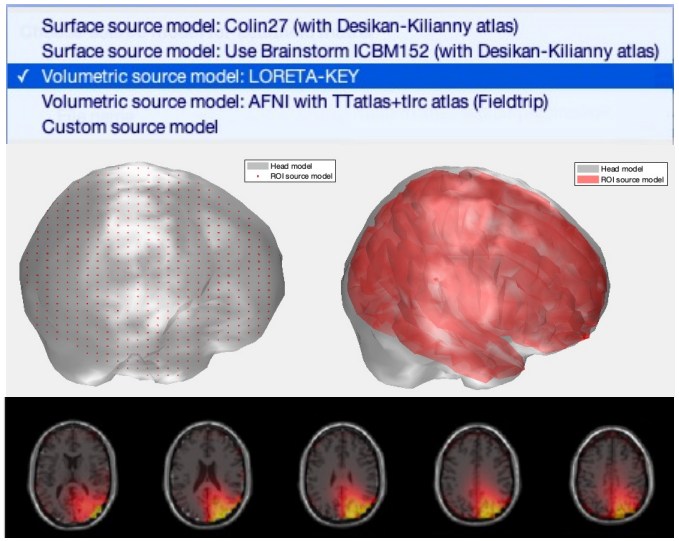


Electrode <-> Head model



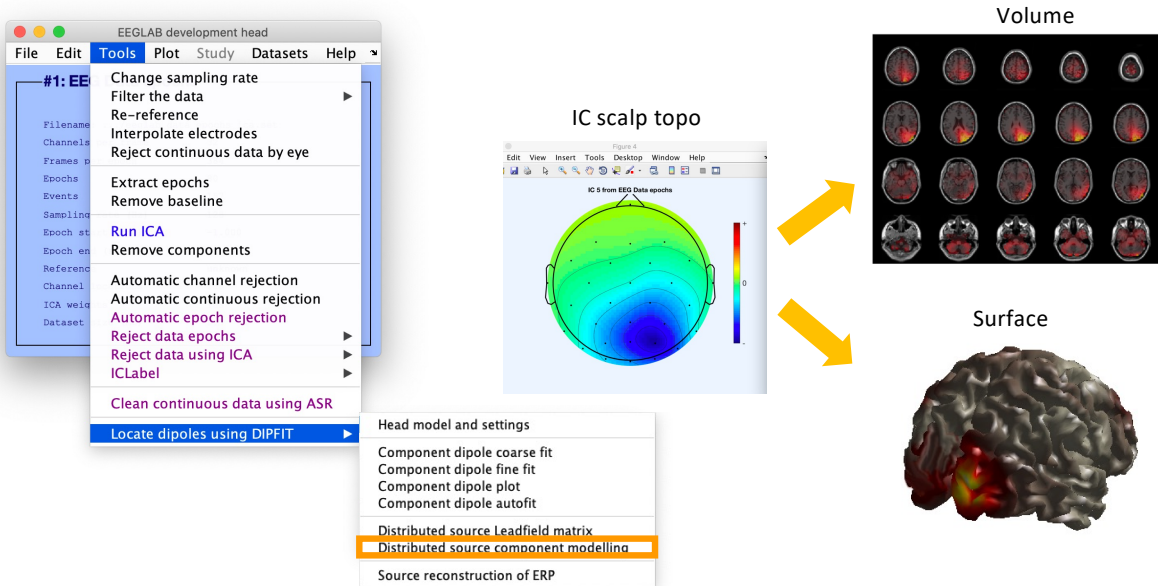
Head model <-> Source model (red)




Surface source model: Colin27 (with Desikan-Kilianny atlas)
Surface source model: Use Brainstorm ICBM152 (with Desikan-Kilianny atlas)
✓ Volumetric source model: LORETA-KEY
Volumetric source model: AFNI with TTatlas+tlrc atlas (Fieldtrip)
Custom source model
Head model
ROI source model
Head model
ROI source model

Distributed source localization

(eloreta or LCMV beamforming)



Exercise

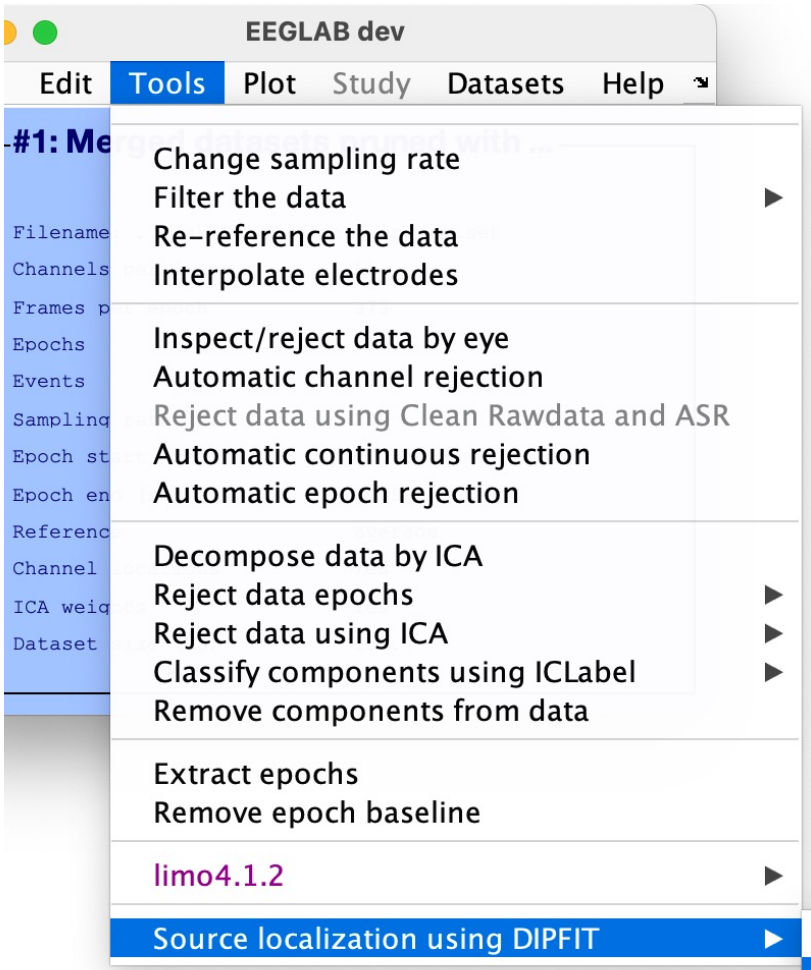
- Compute Leadfield matrix using menu item

Source localization using DIPFIT > Compute Leadfield matrix

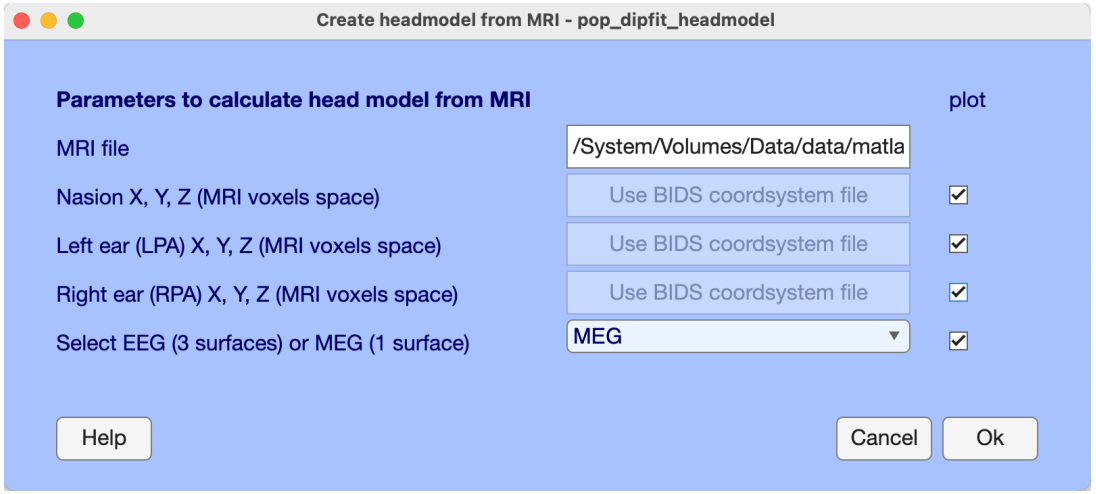
- Compute eLoreta solution for component 3 using menu item

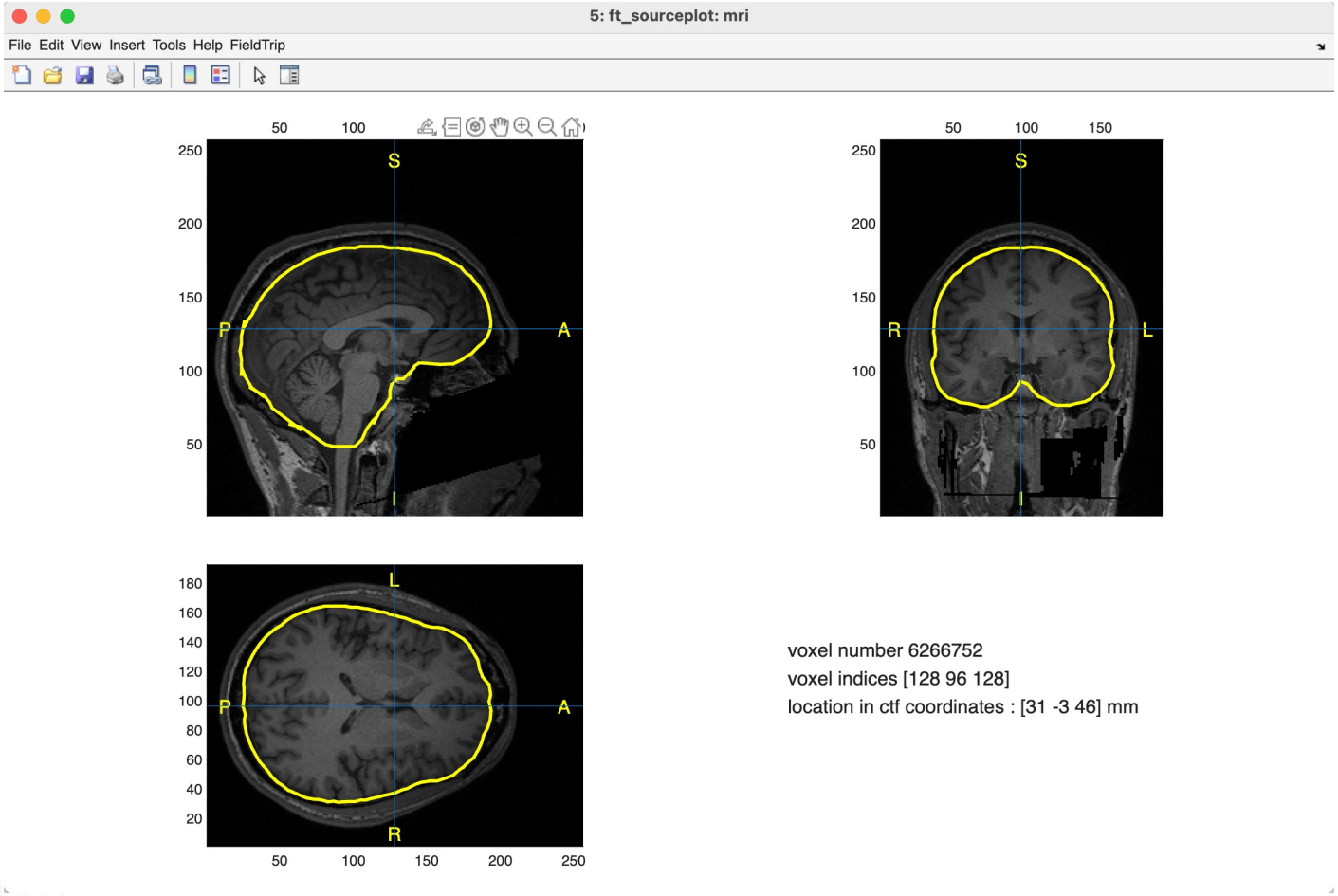
Source localization using DIPFIT > Distributed Source Component Modeling

Realistic fit

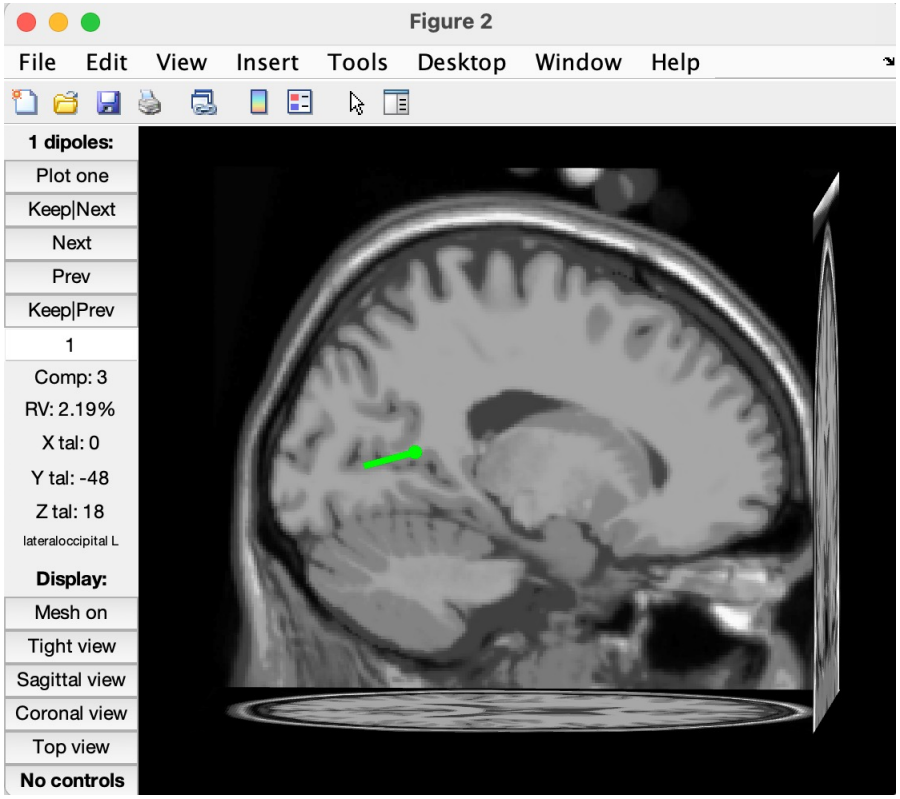


use file "ds000117_pruned/sub-01/mri/anat/sub-01_ses-mri_acq-mprage_T1w.nii.gz"

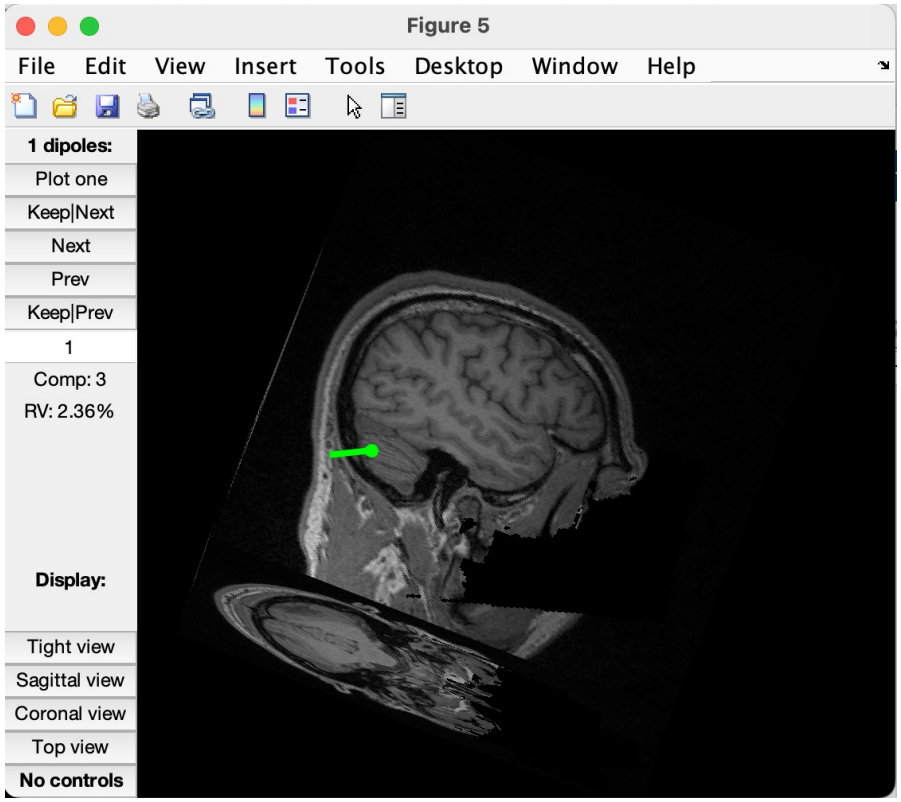



5: ft_sourceplot: mri
File Edit View Insert Tools Help FieldTrip
S
P
A
I
S
R
L
I
L
P
A
R
voxel number 6266752
voxel indices [128 96 128]
location in ctf coordinates : [31 -3 46] mm

Template



Subject's brain



Anatomical MRI of subject should be normalized to MNI first using SPM (group analysis, atlas etc…)