UTHealth®

McGovern Medical School

The University of Texas Health Science Center at Houston

Reconstructing Neural Sources of Activity from SEEG Recordings

(All models are wrong, but some are useful)

Prof. John C. Mosher

Texas Institute for Restorative Neurotechnologies (TIRN)
Department of Neurology

Outline

All models are wrong, but some are useful.

-*George Box*

- Physiological basis of the **Current Column**
- Modeling of the cortical surface
- Invasive Source Modeling

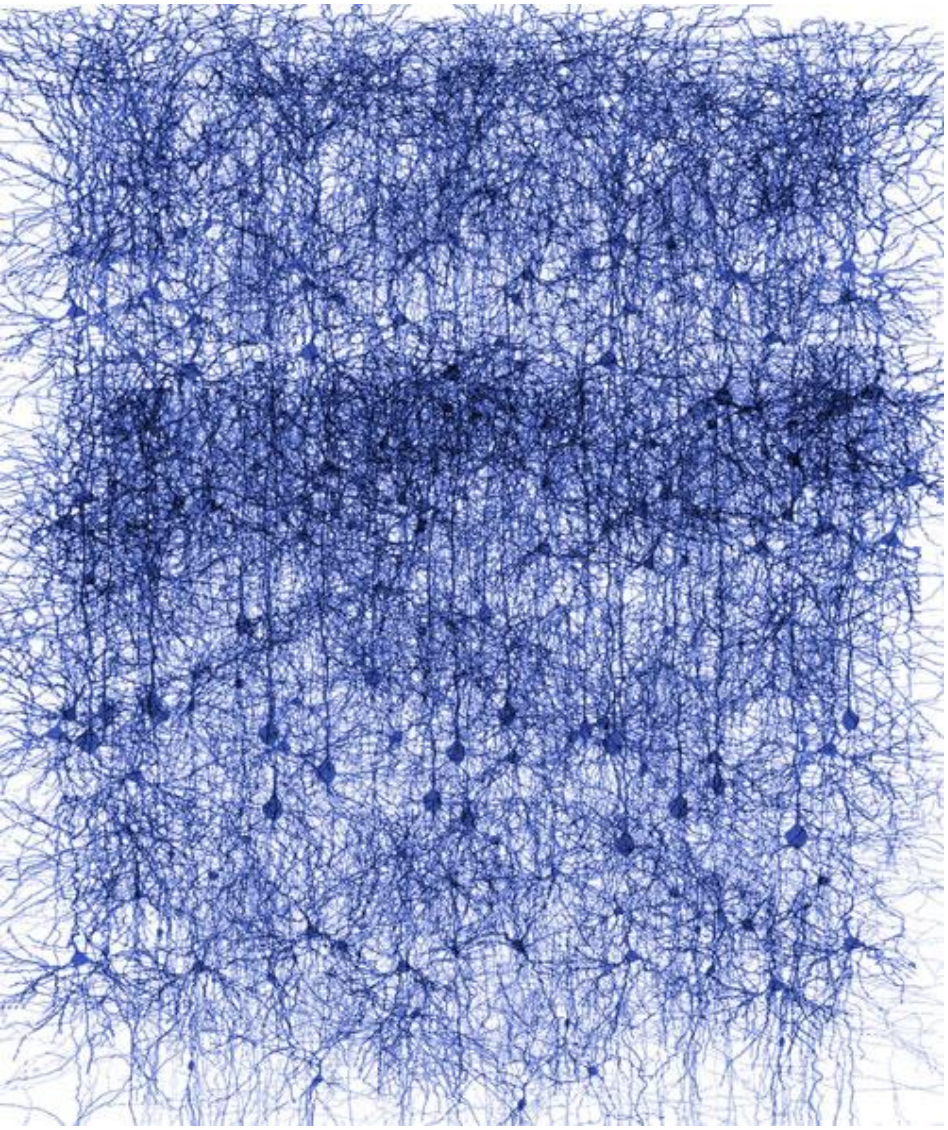
Outline

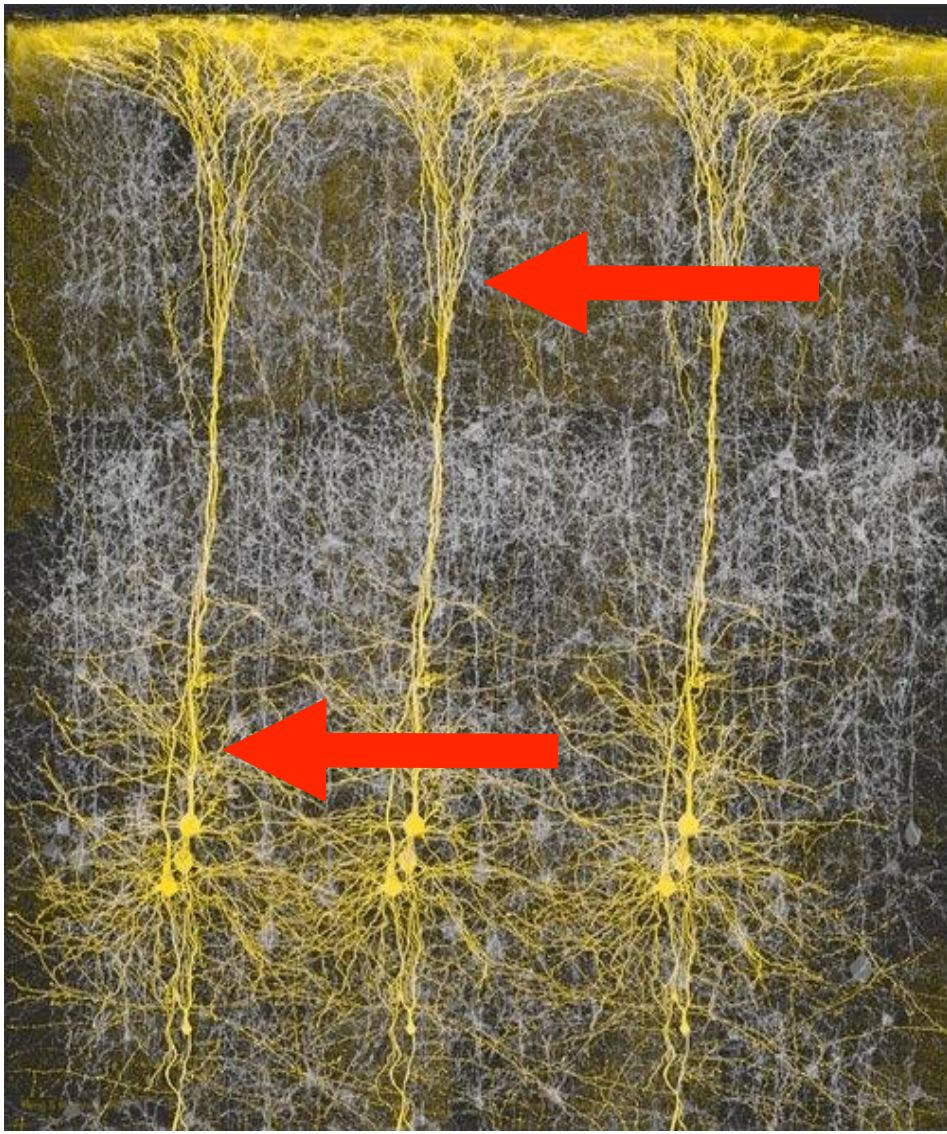
All models are wrong, but some are useful.

-*George Box*

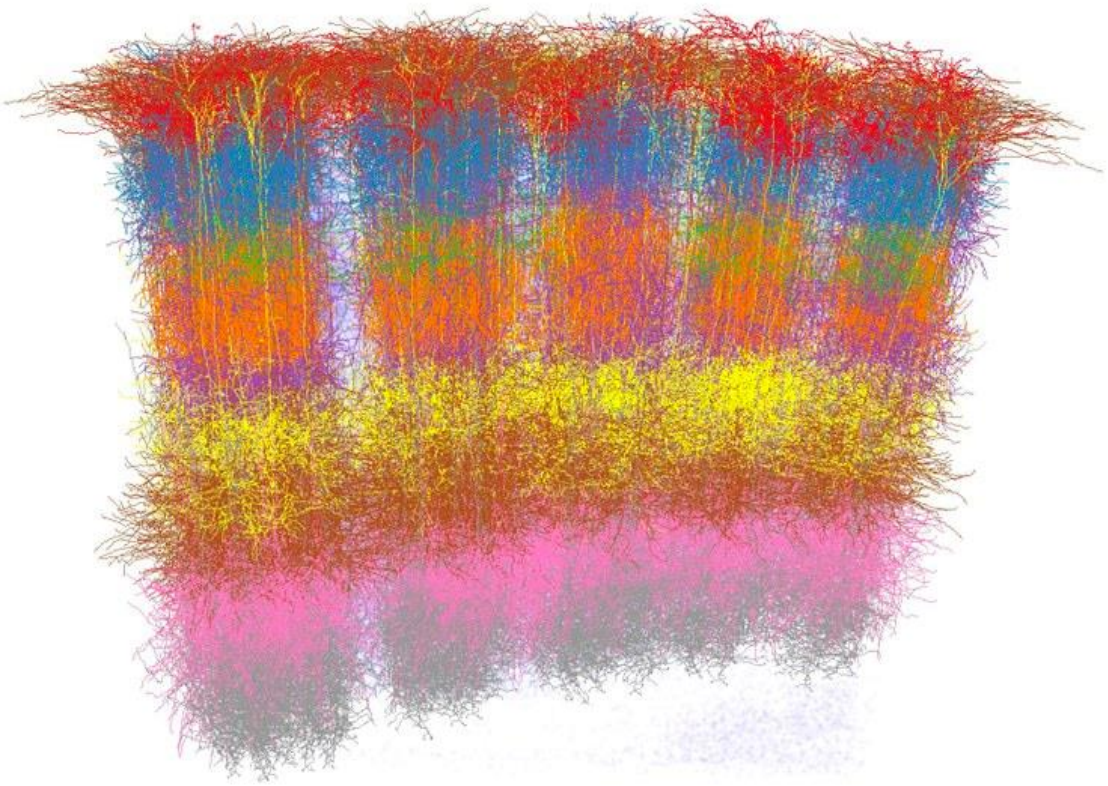
- **Physiological basis of the Current Column**
- Modeling of the cortical surface
- Invasive Source Modeling

A Forest of Neurons in Gray Matter





“Cortical Columns”



- Model the 3D multilayer cortex as columns.
- Emphasize the 2D cortical surface in units of square mm
- This “wrong” model ignores the complexity of the column and the transverse connections.

Cell-type-specific 3D reconstruction of five neighboring barrel columns in rat vibrissal cortex (credit: Marcel Oberlaender et al.)

Excitatory vs Inhibitory PSP

- Ambiguous whether excitatory in upper layers or inhibitory in lower layers.

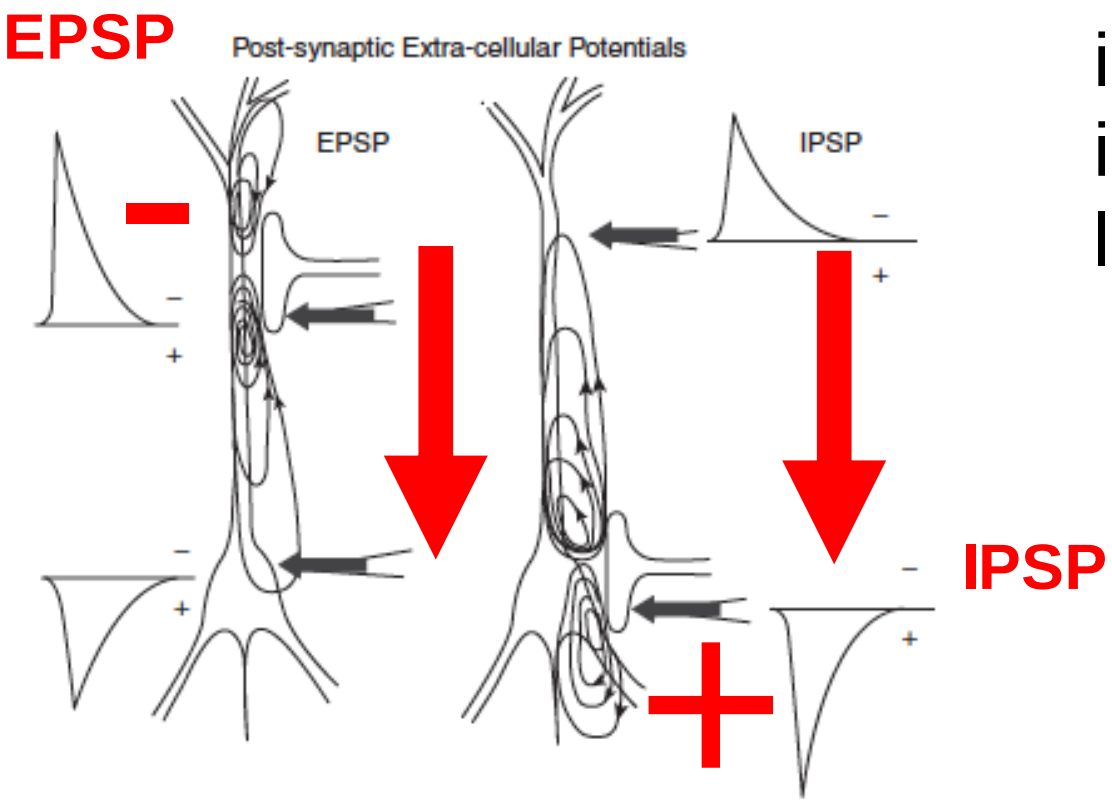
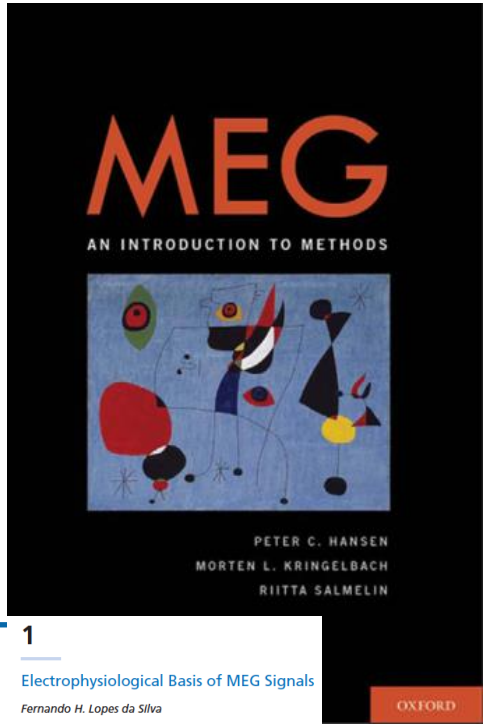
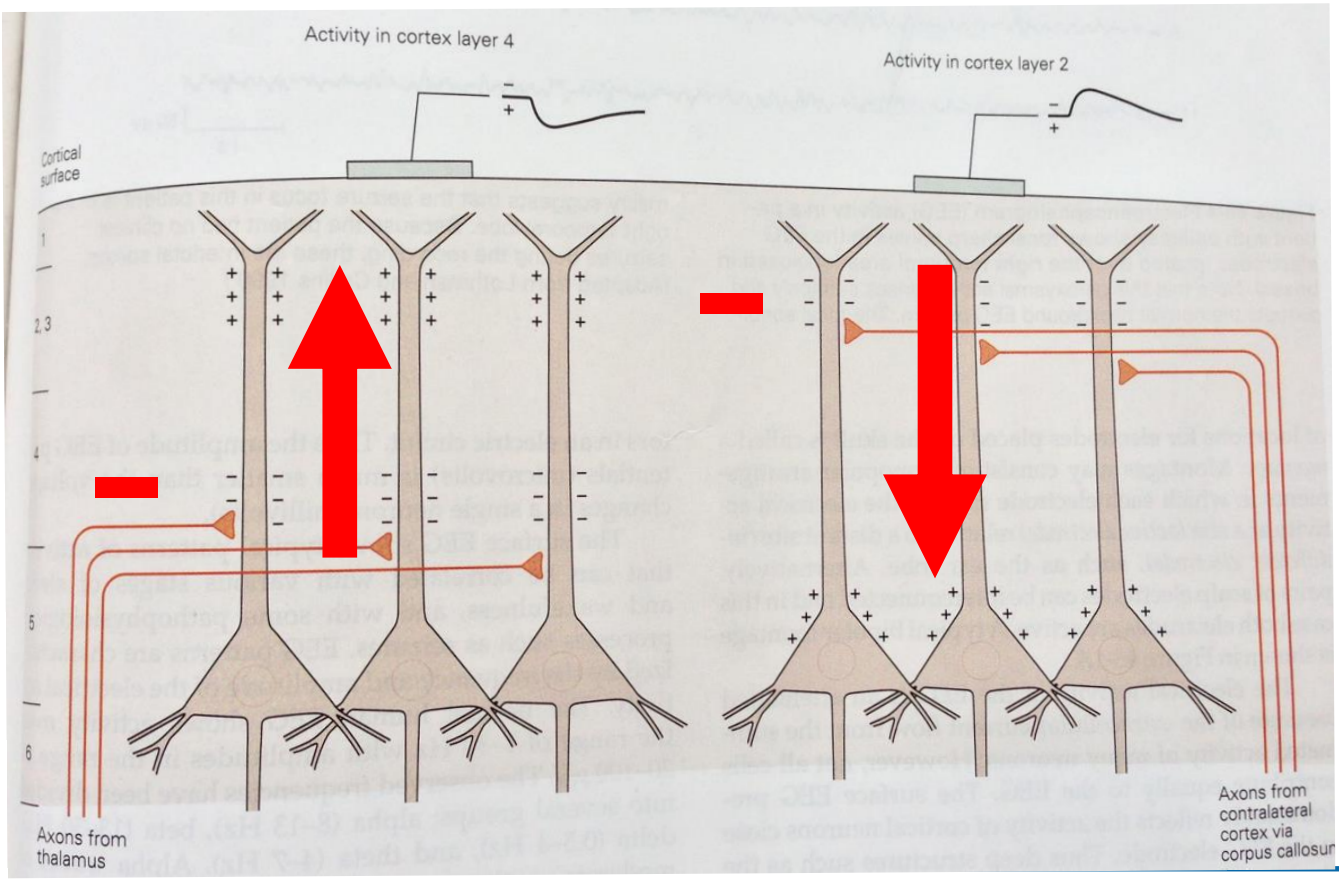


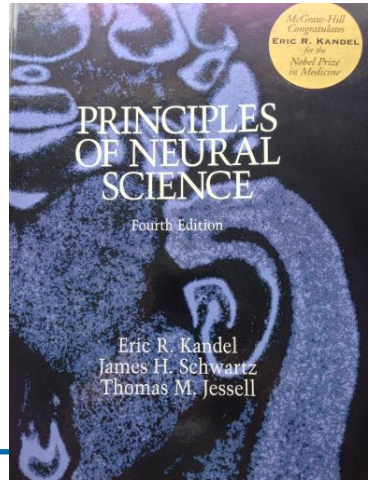
Figure 1–1. Intra- and extracellular current flow in an idealized pyramidal neuron due to different types of synaptic activation. EPSP: excitatory



EPSP Distal vs Proximal

- Thalamo-cortical into Layer 4 -> **Upwards**
- Contralateral-cortical into Layer 2,3 -> **Downwards**





Cortex is NOT Columnar EVERYWHERE

(But good enough for now)

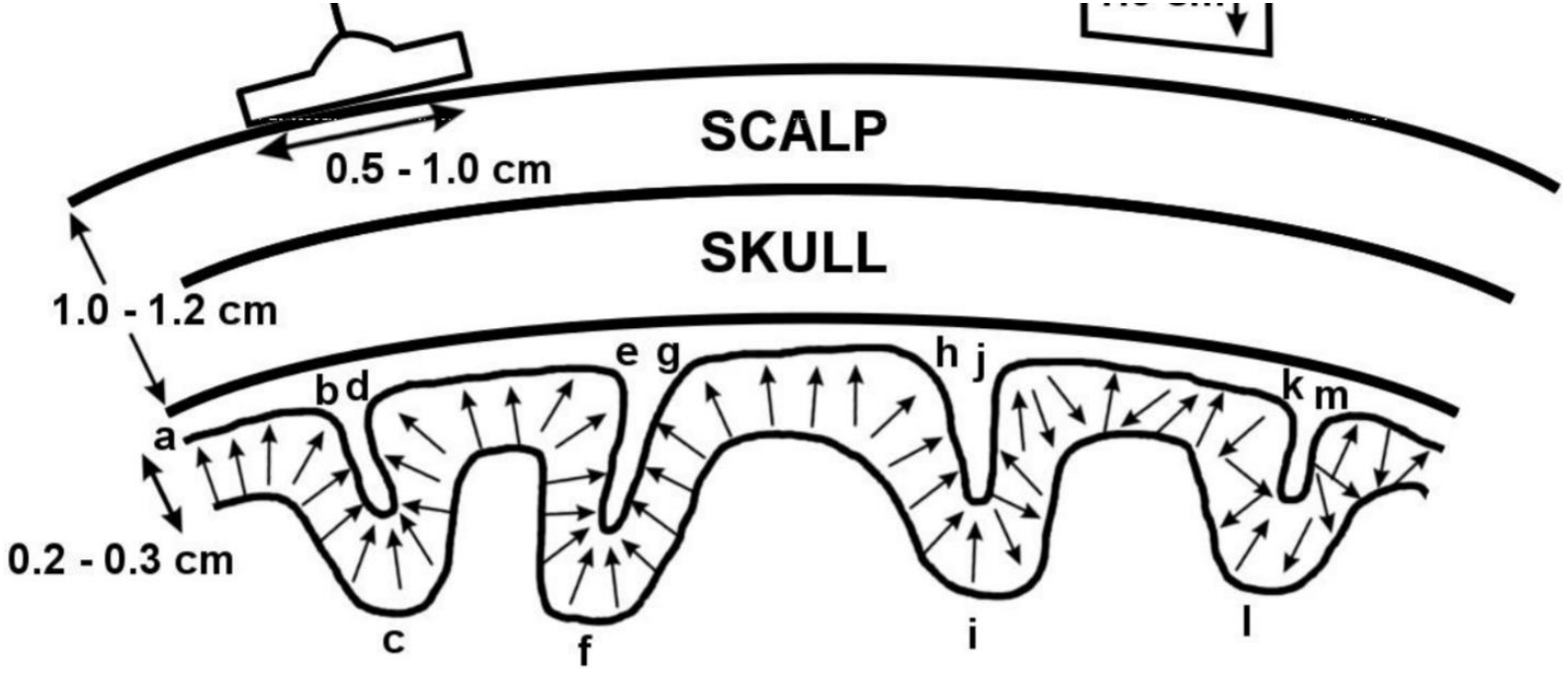


Figure 4. Cortical dipole layers. The arrows represent a snapshot of the macro source function $\mathbf{P}(\mathbf{r}, t)$, which is here assumed to be synchronous and directed perpendicular to the local cortical surface over the extended region a-i. In contrast, $\mathbf{P}(\mathbf{r}, t)$ has random directions in regions i-m.

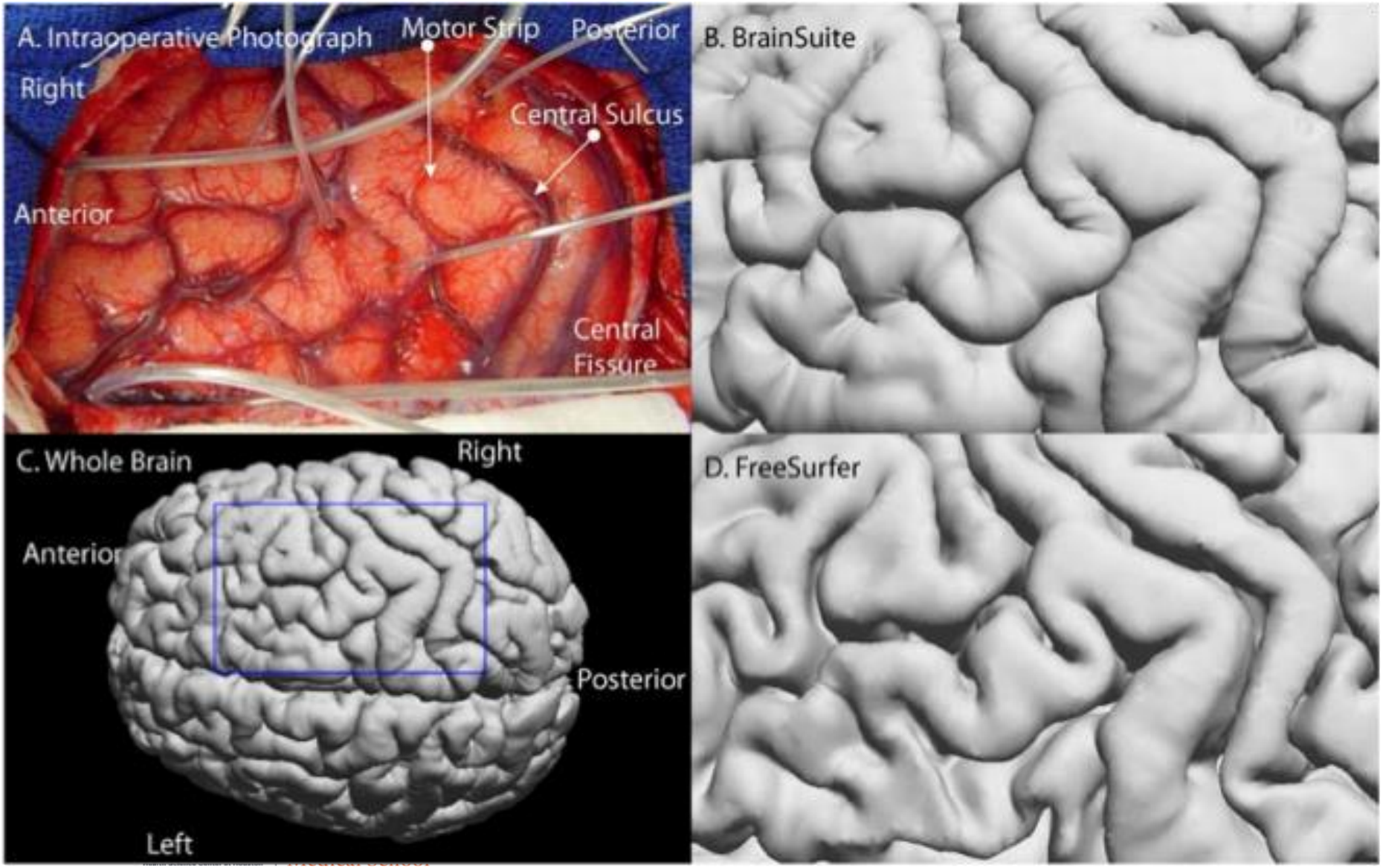
Outline

All models are wrong, but some are useful.

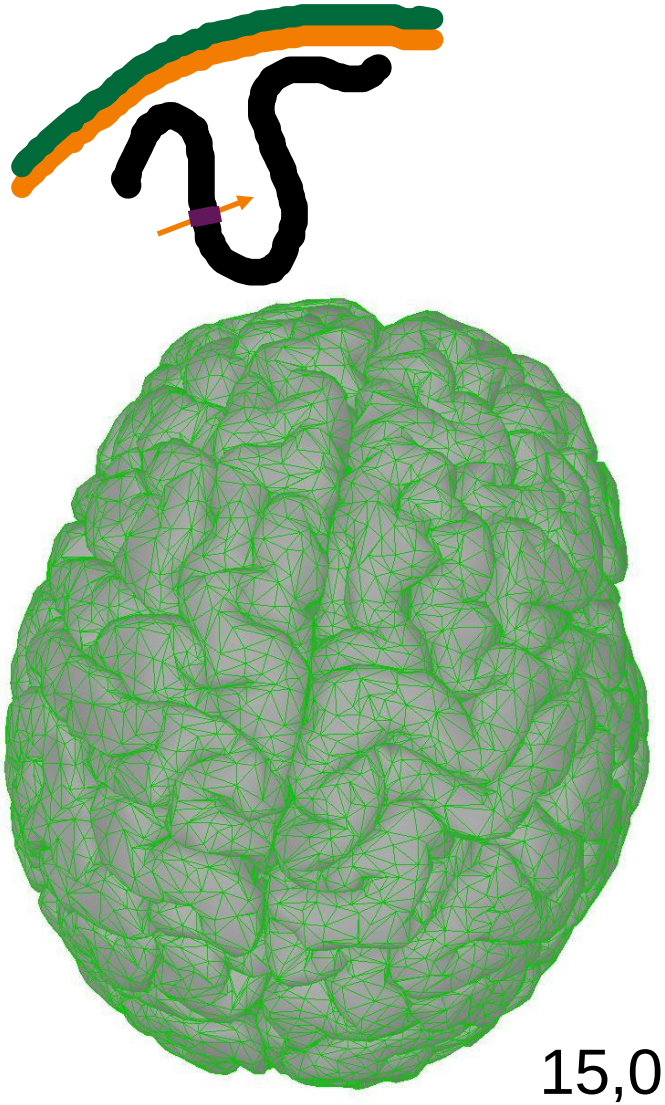
-*George Box*

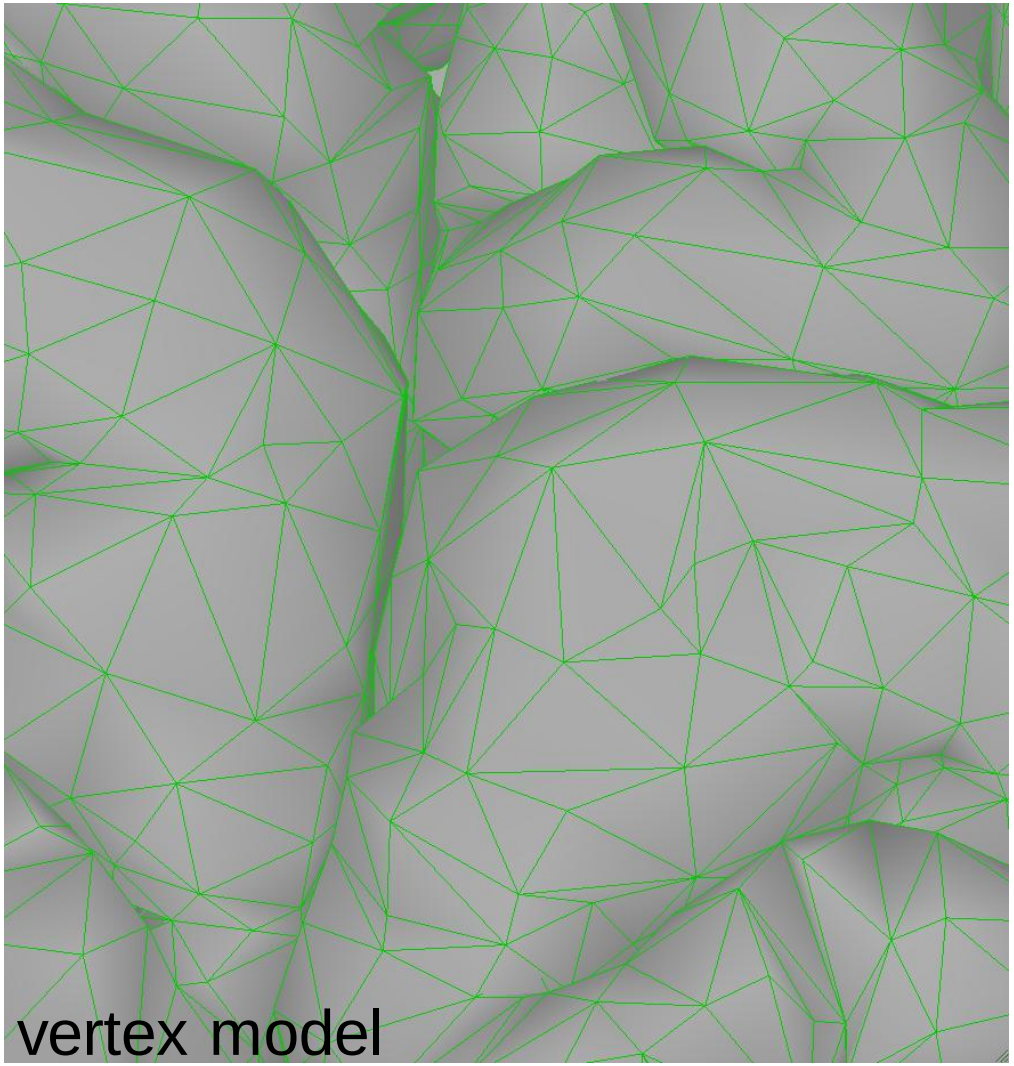
- Physiological basis of the **Current Column**
- **Modeling of the cortical surface**
- Invasive Source Modeling

Cortical Surface



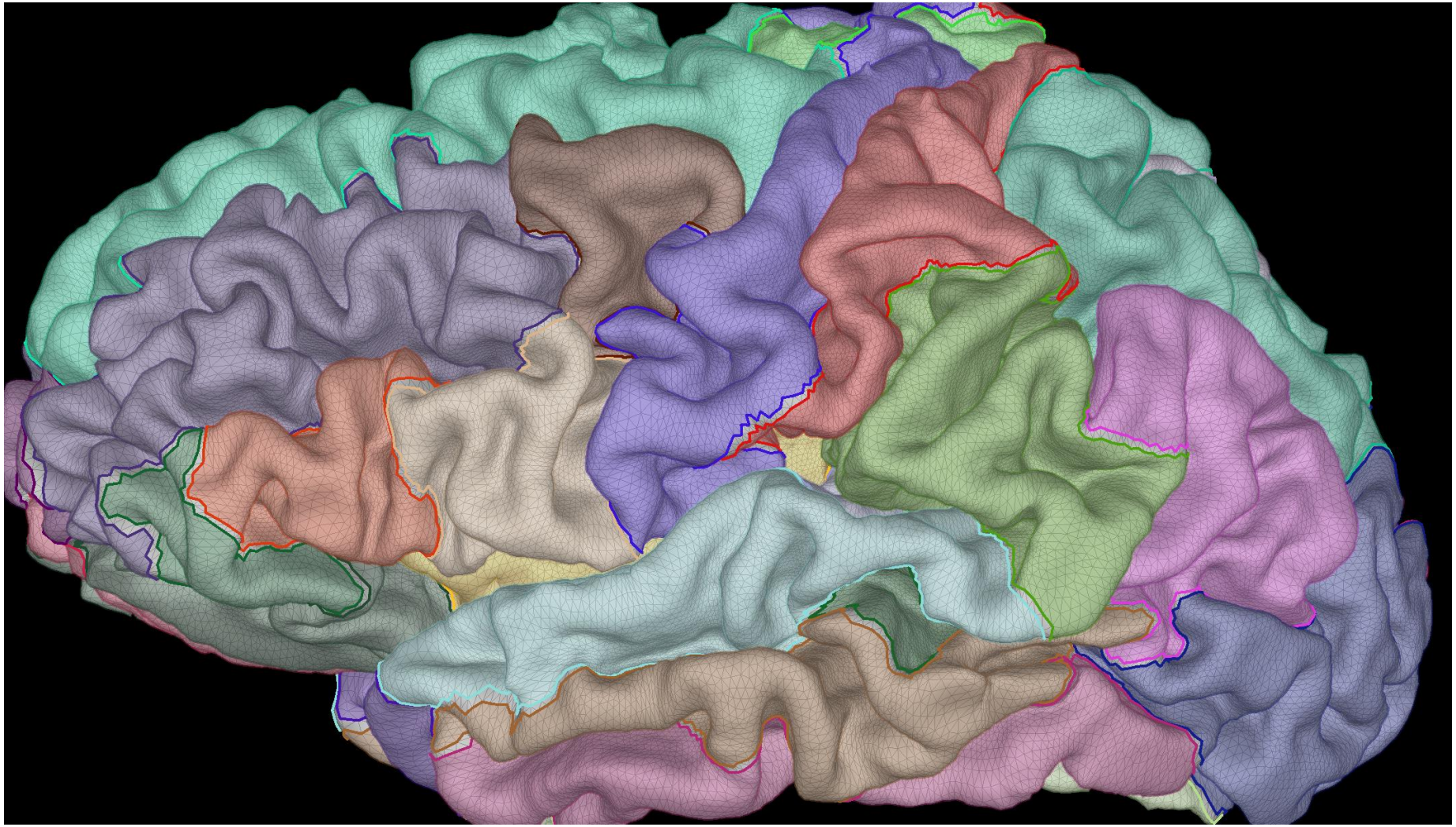
Cortical Modeling of Sources – Thousands of triangles





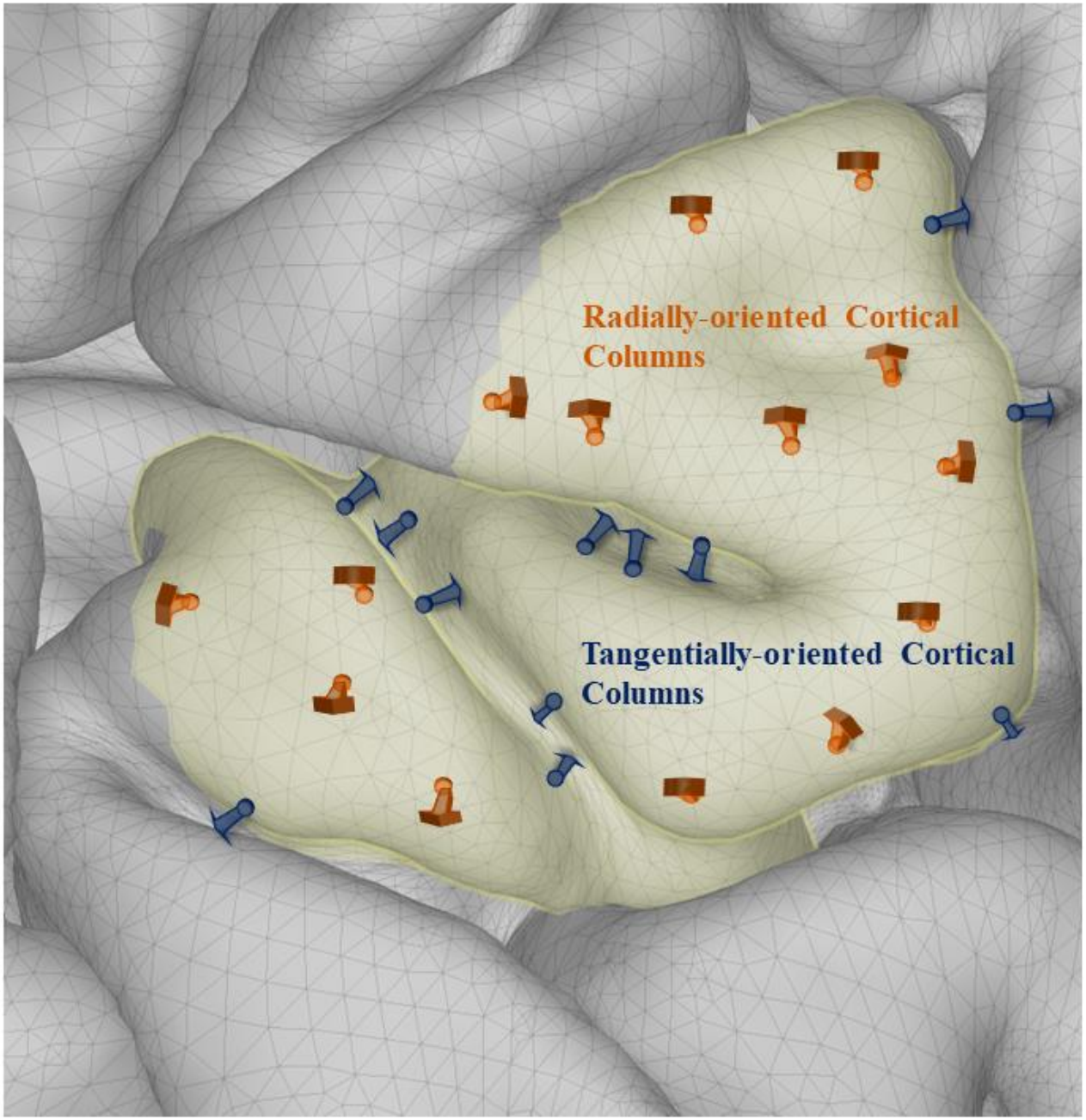
15,000 vertex model

252,224 labeled vertices spanning 192,152 square mm



Freesurfer, 269,161 verts total, 538,314 faces, nearly a perfect surface

Each Vertex Models an ~1 square mm Cortical Column



Outline

All models are wrong, but some are useful.

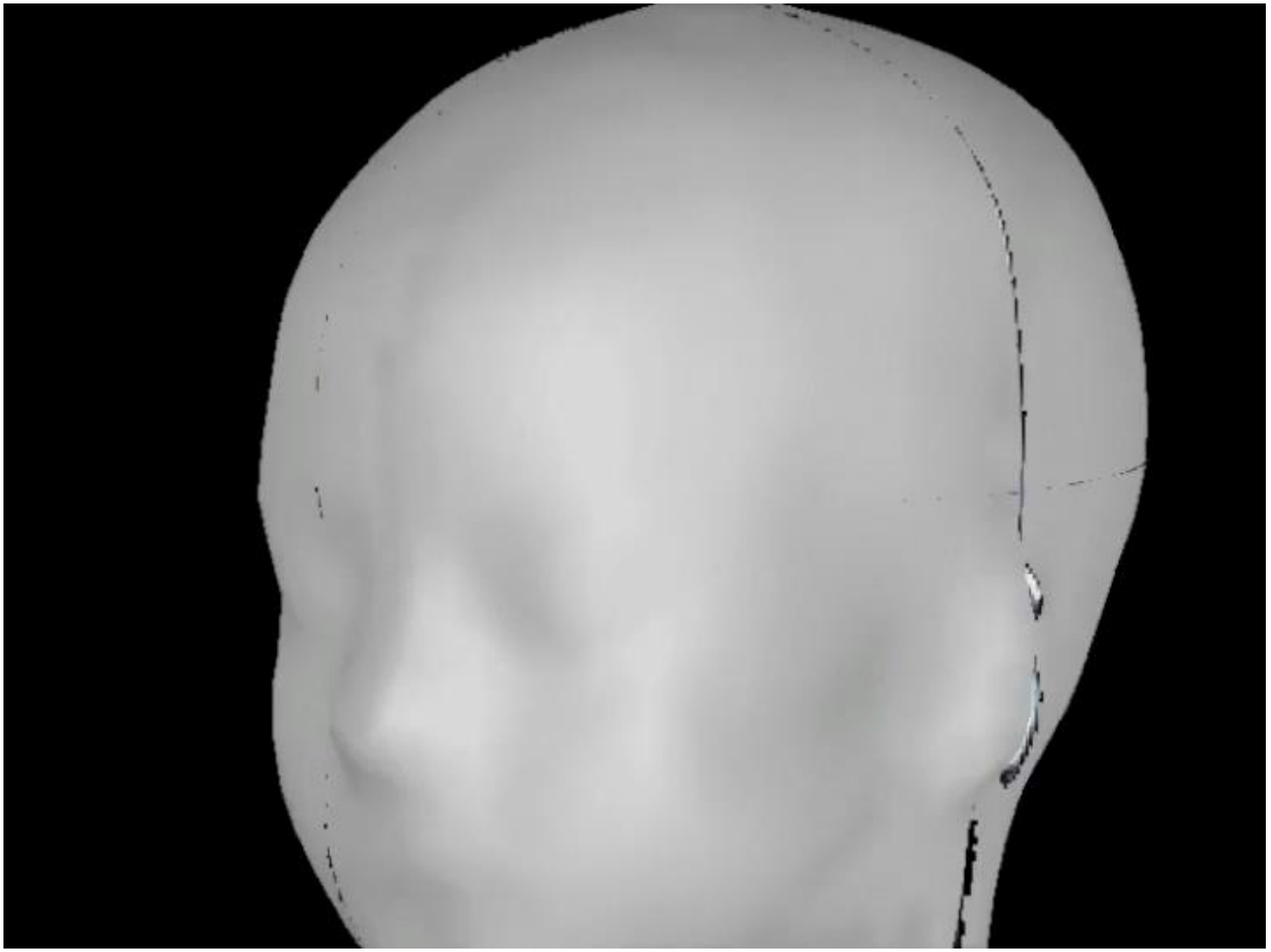
-*George Box*

- Physiological basis of the **Current Column**
- Modeling of the cortical surface
- **Invasive Source Modeling**

Brainstorm SEEG

- SEEG Contacts are registered to the PT anatomy
- Contacts are visualized life-size
- Brainstorm tutorial on how to do in your facility

Brainstorm SEEG Processing



Good Coverage is Important!

Epilepsy Research 128 (2016) 68–72

Contents lists available at www.sciencedirect.com

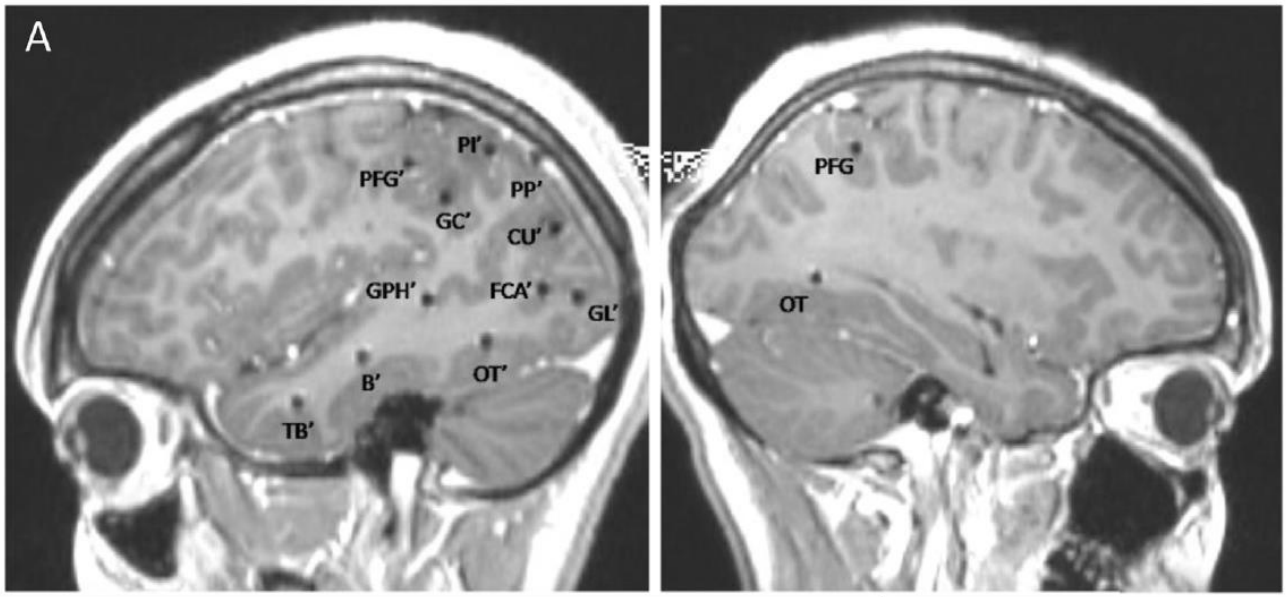
Epilepsy Research

journal homepage: www.elsevier.com/locate/epilepsyres

Short communication

Simultaneous SEEG-MEG-EEG recordings Overcome the SEEG limited spatial sampling

Martine Gavaret[a,b], Anne-Sophie Dubarry[a,c], Romain Carron[a,d], Fabrice Bartolomei[a,b], Agnès Trébuchon[a,b,1], Christian-George Bénar[a,*,1]



MEG Localized

Epilepsy Research 128 (2016) 68–72

Contents lists available at www.sciencedirect.com

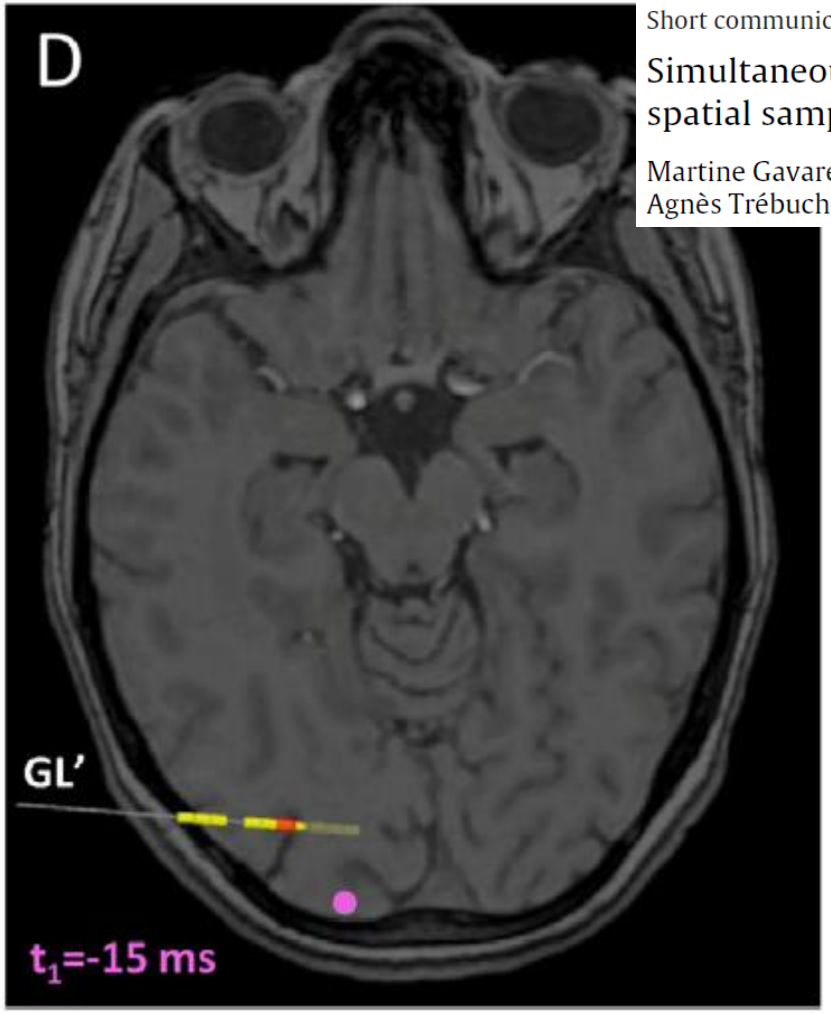
Epilepsy Research

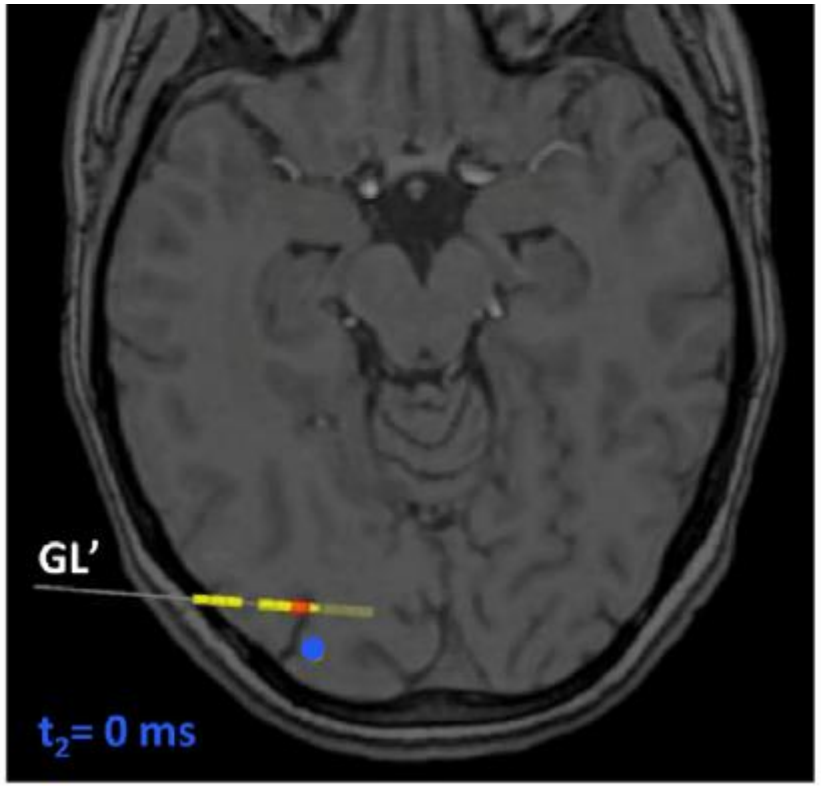
journal homepage: www.elsevier.com/locate/epilepsyres

Short communication

Simultaneous SEEG-MEG-EEG recordings Overcome the SEEG limited spatial sampling

Martine Gavaret[a,b], Anne-Sophie Dubarry[a,c], Romain Carron[a,d], Fabrice Bartolomei[a,b], Agnès Trébuchon[a,b,1], Christian-George Bénar[a,*,1]





UTHealth The University of Texas Health Science Center at Houston | McGovern Medical School

Excellent Reference Paper on Good Practices

NeuroImage 260 (2022) 119438

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

Advances in human intracranial electroencephalography research, guidelines and good practices

Manuel R. Mercier[a,*], Anne-Sophie Dubarry[b], François Tadel[c], Pietro Avanzini[d], Nikolai Axmacher[e,f], Dillan Cellier[g], Maria Del Vecchio[d], Liberty S. Hamilton[h,i,j], Dora Hermes[k], Michael J. Kahana[l], Robert T. Knight[m], Anais Llorens[n], Pierre Megevand[o], Lucia Melloni[p,q], Kai J. Miller[r], Vitória Piai[s,t], Aina Puce[u], Nick F Ramsey[v], Caspar M. Schwiedrzik[w,x], Sydney E. Smith[y], Arjen Stolk[s,z], Nicole C. Swann[aa], Mariska J Vansteensel[v], Bradley Voytek[g,y,ab,ac], Liang Wang[ad,ae], Jean-Philippe Lachaux[af,1], Robert Oostenveld[s,ag,1]

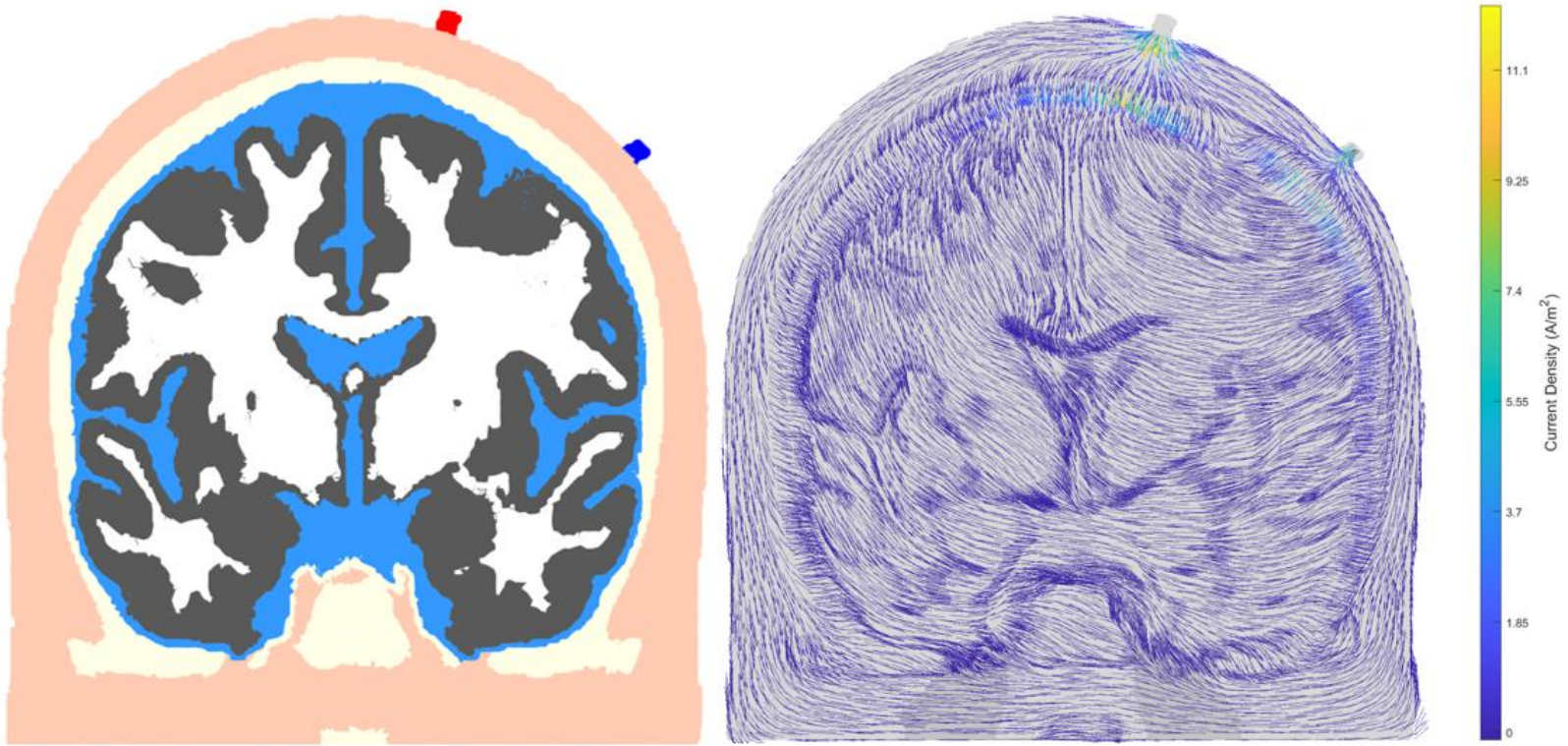
Example Case Study

- PT has PMG (polymicrogyria) in the right peri-rolandic region, suspected seizure onset site
- 17 devices (‘electrodes’) implanted, comprising about 250 electrodes (‘channels,’ ‘contacts’).
- Surface modeling of the “mid” surface between pial and gray/white boundaries.
- (VLC Movie)

Leadfield Analyses

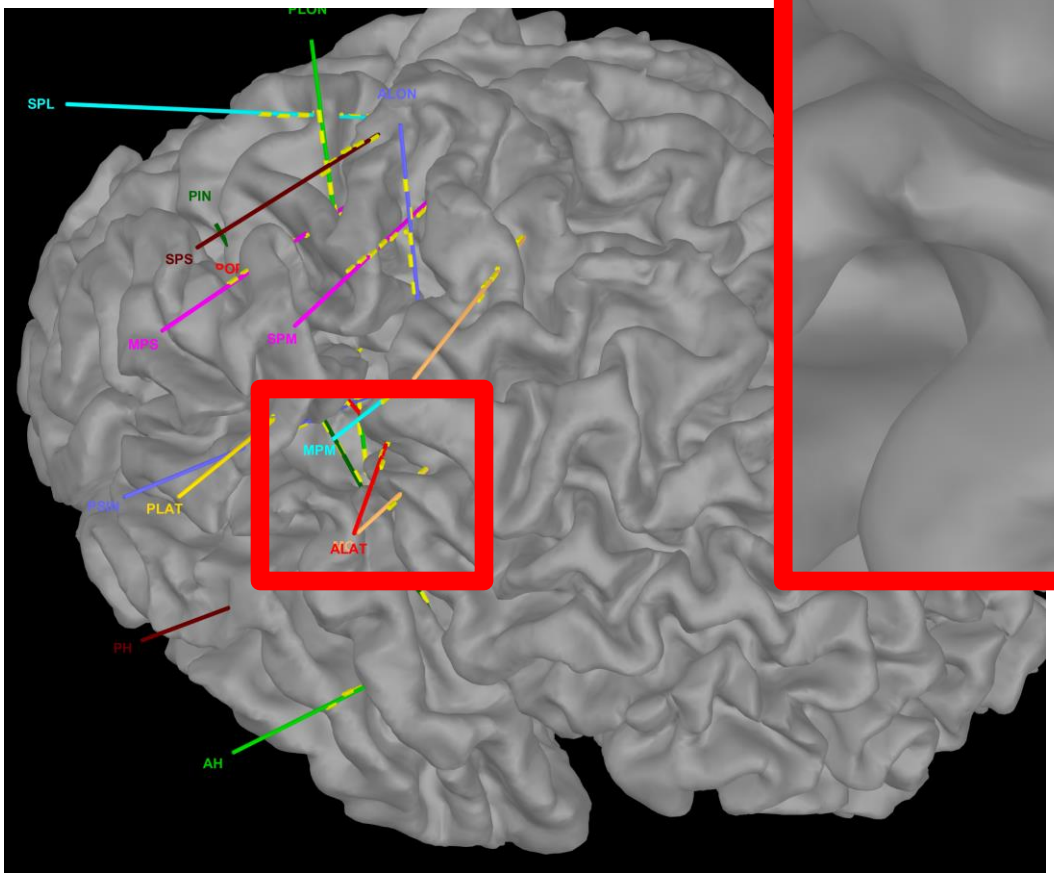
- In this example, the cortical surface comprises ~270,000 vertices, and we have ~250 SEEG contacts.
- For each of the vertices, we calculate the forward model to all contacts.
  - OpenMEEG or DuneNEURO
  - Forward model calculated in x, y, and z directions.
  - Forward matrix is 250 x 3 for each vertex.
- The result is a matrix of size 250 x 810,000.
  - Only a few GB at single precision.
- By reciprocity, each ROW of this matrix represents samples of the leadfields for that contact.

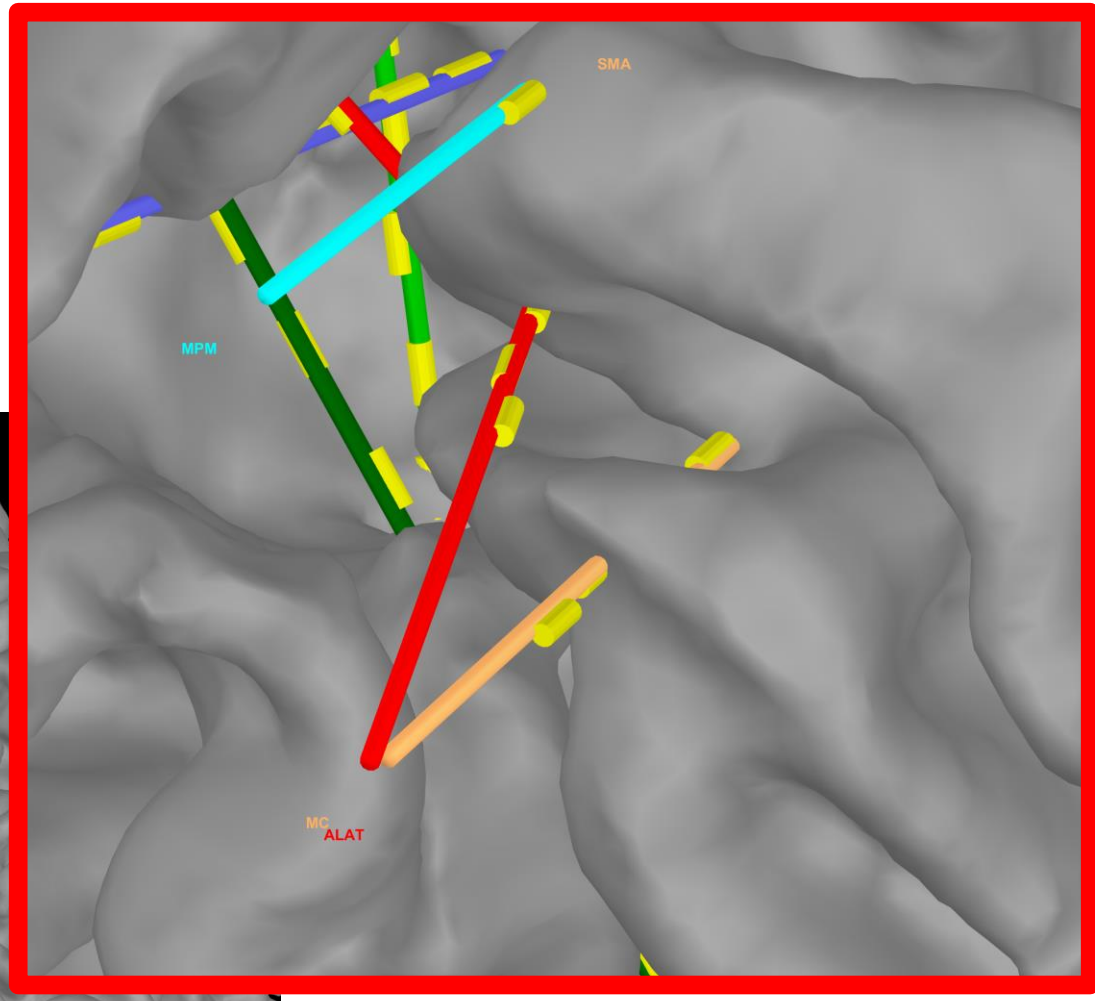
FEM Lead-Fields in a Five Compartment Model



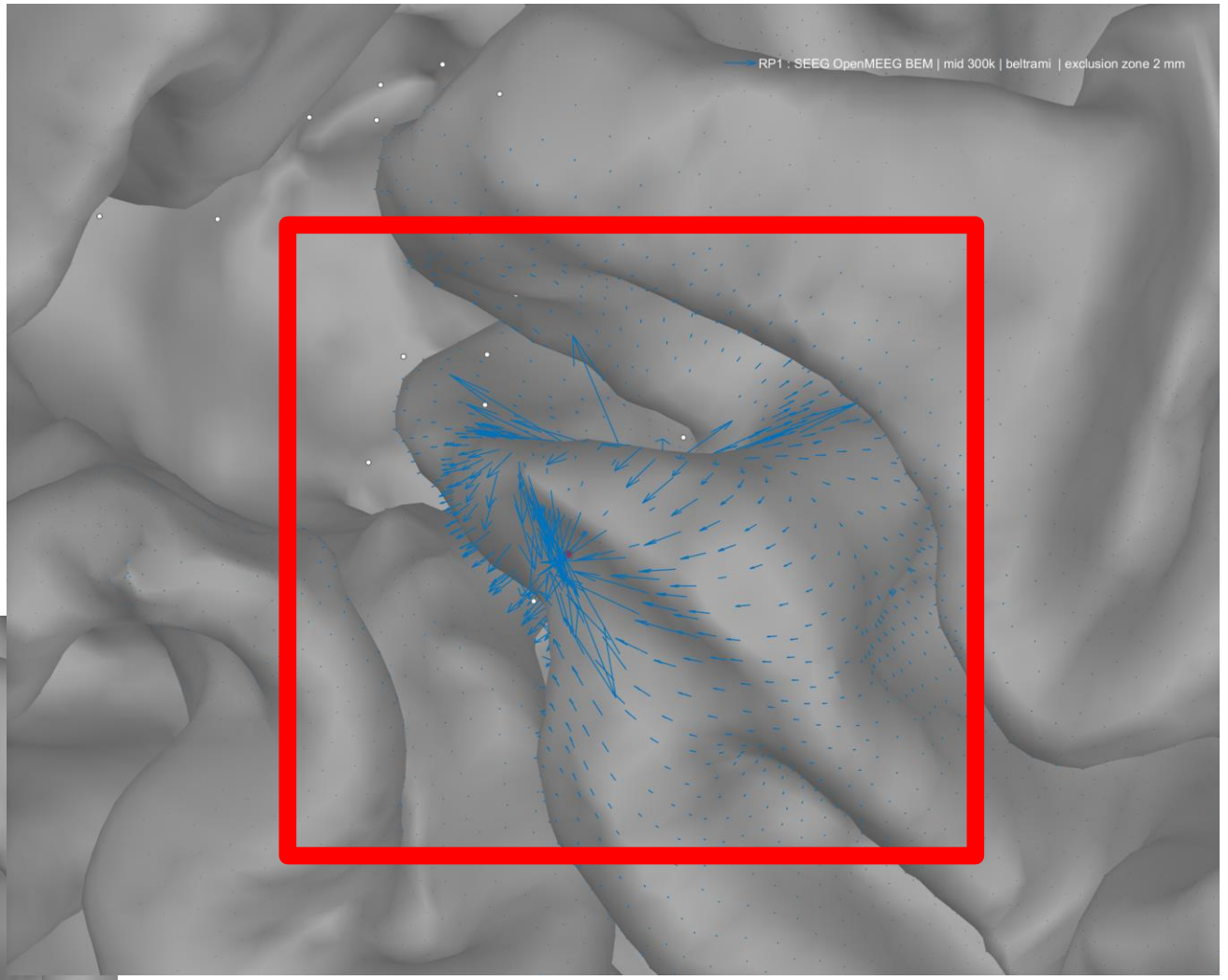
- DUNEuro – Brainstorm implementation.
  - Duneuro is based on the DUNE library (distributed and unified numerics environment)
  - Brainstorm provides a Matlab interface to duneuro
  - Example here is the lead fields through a five isotropic compartment
  - REF: Duneuro.org and neuroimage.usc.edu/brainstorm

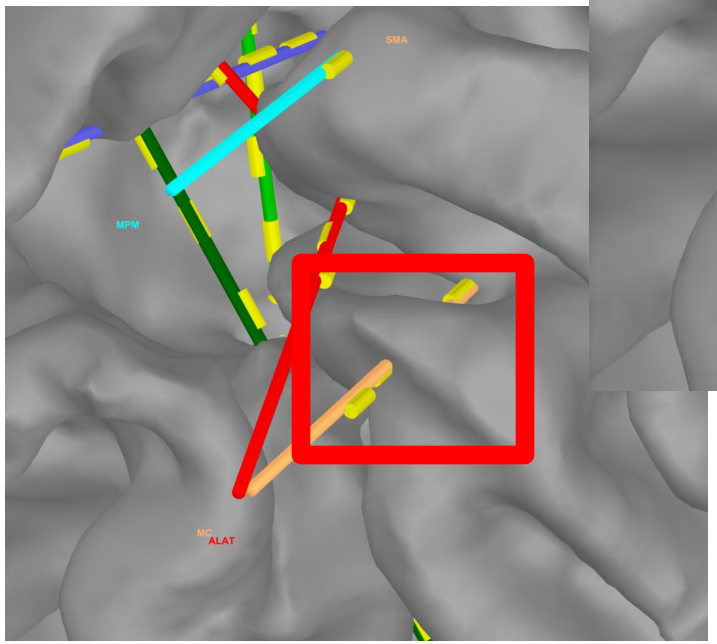
Leadfields



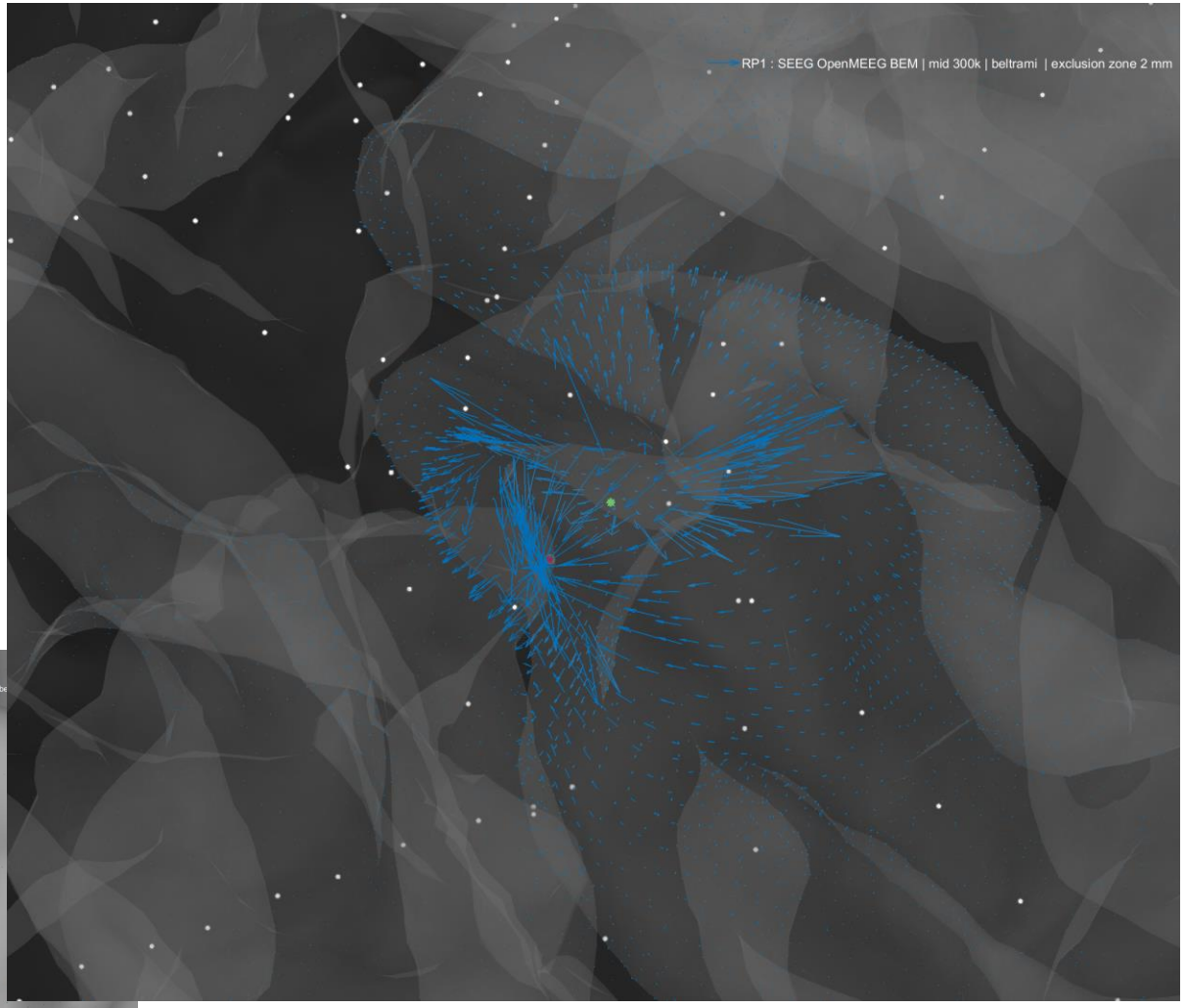


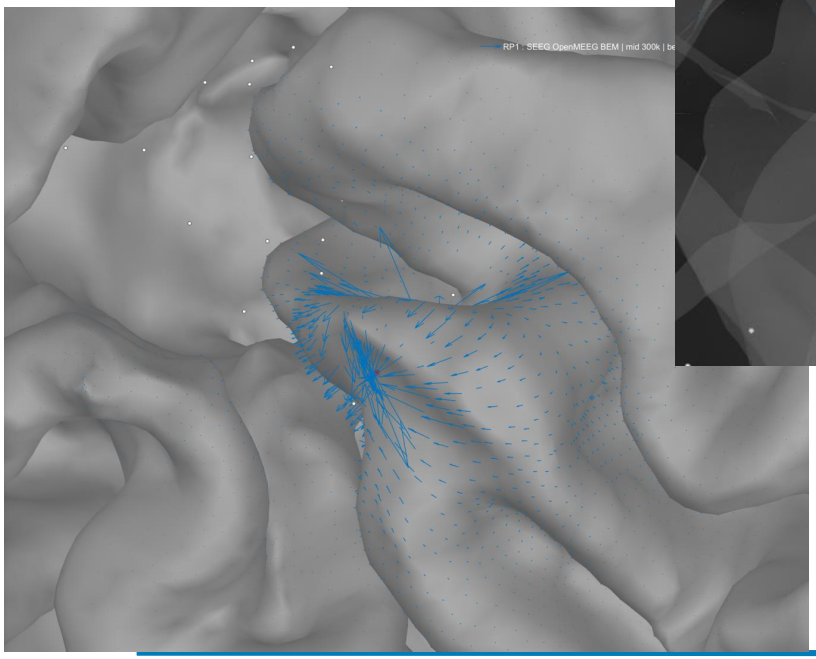
Leadfields


RP1 : SEEG OpenMEEG BEM | mid 300k | beltrami | exclusion zone 2 mm

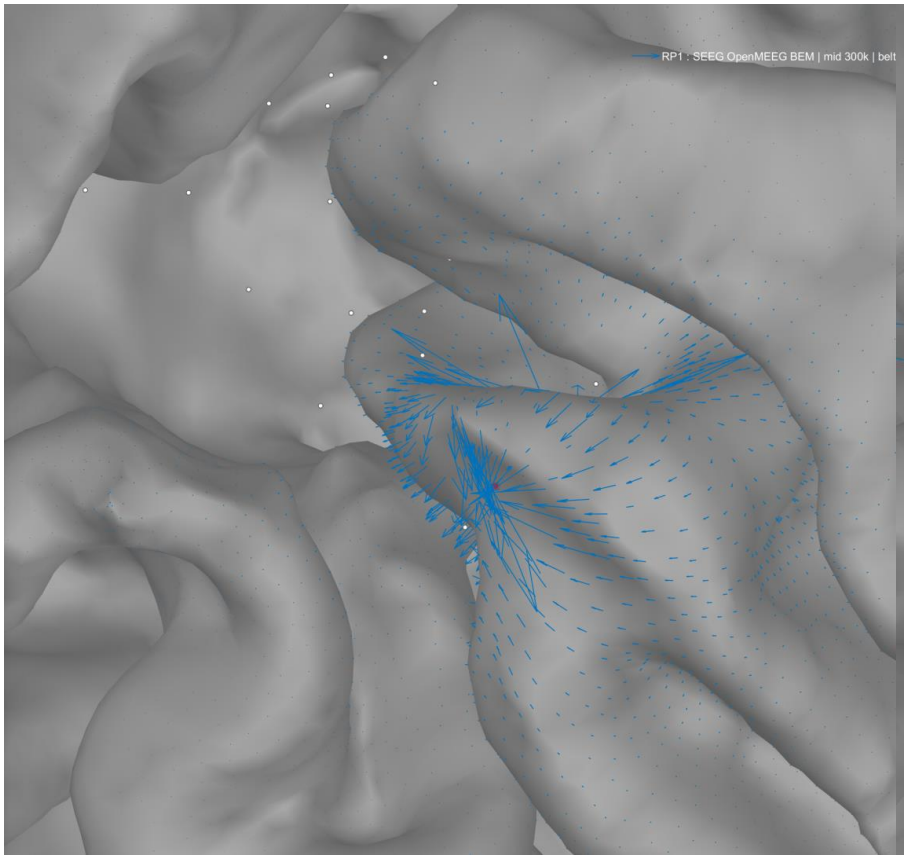

SMA
MPM
MC
ALAT

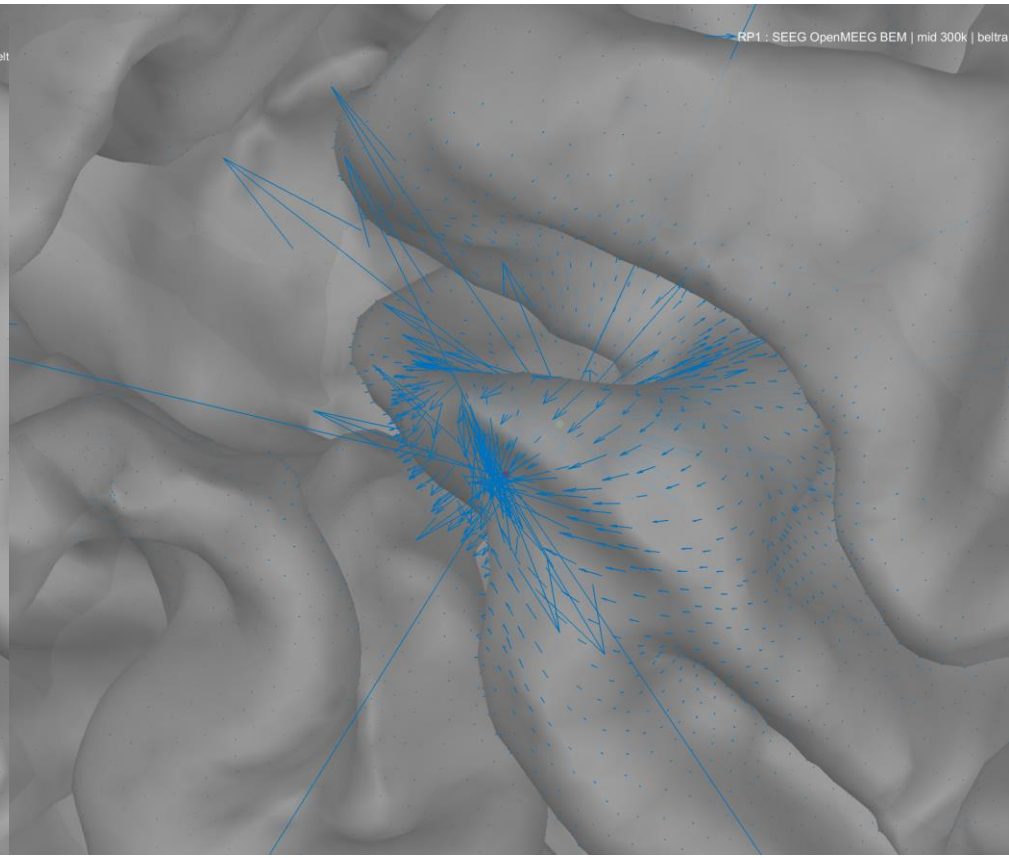
Leadfields





Numeric Instabilities Need Trimming

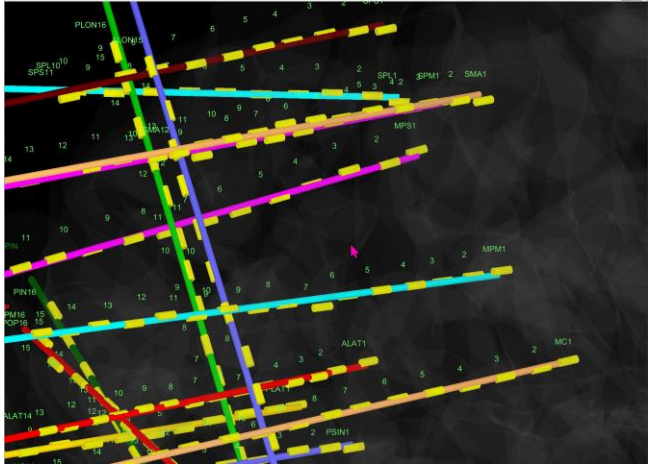




2mm Exclusion Zone

No Exclusion Zone

Stepping through Leadfields

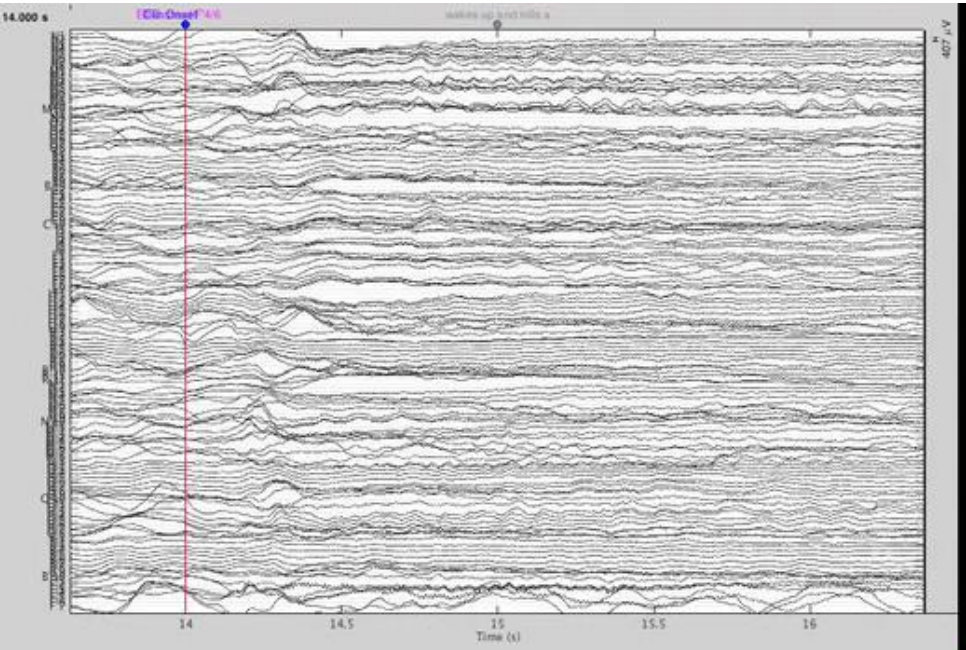


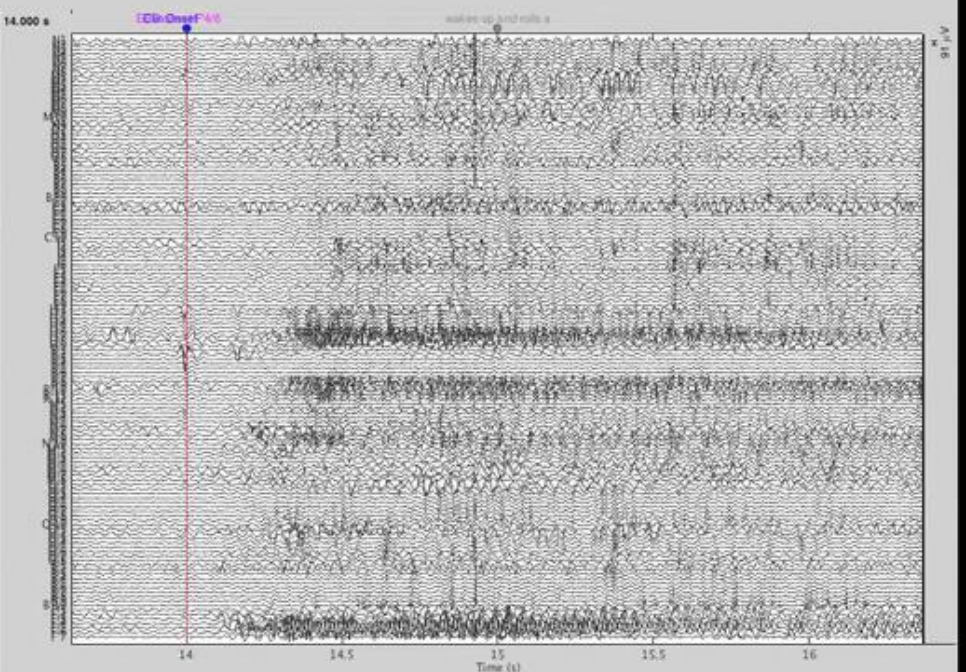
- (VLC Movie)

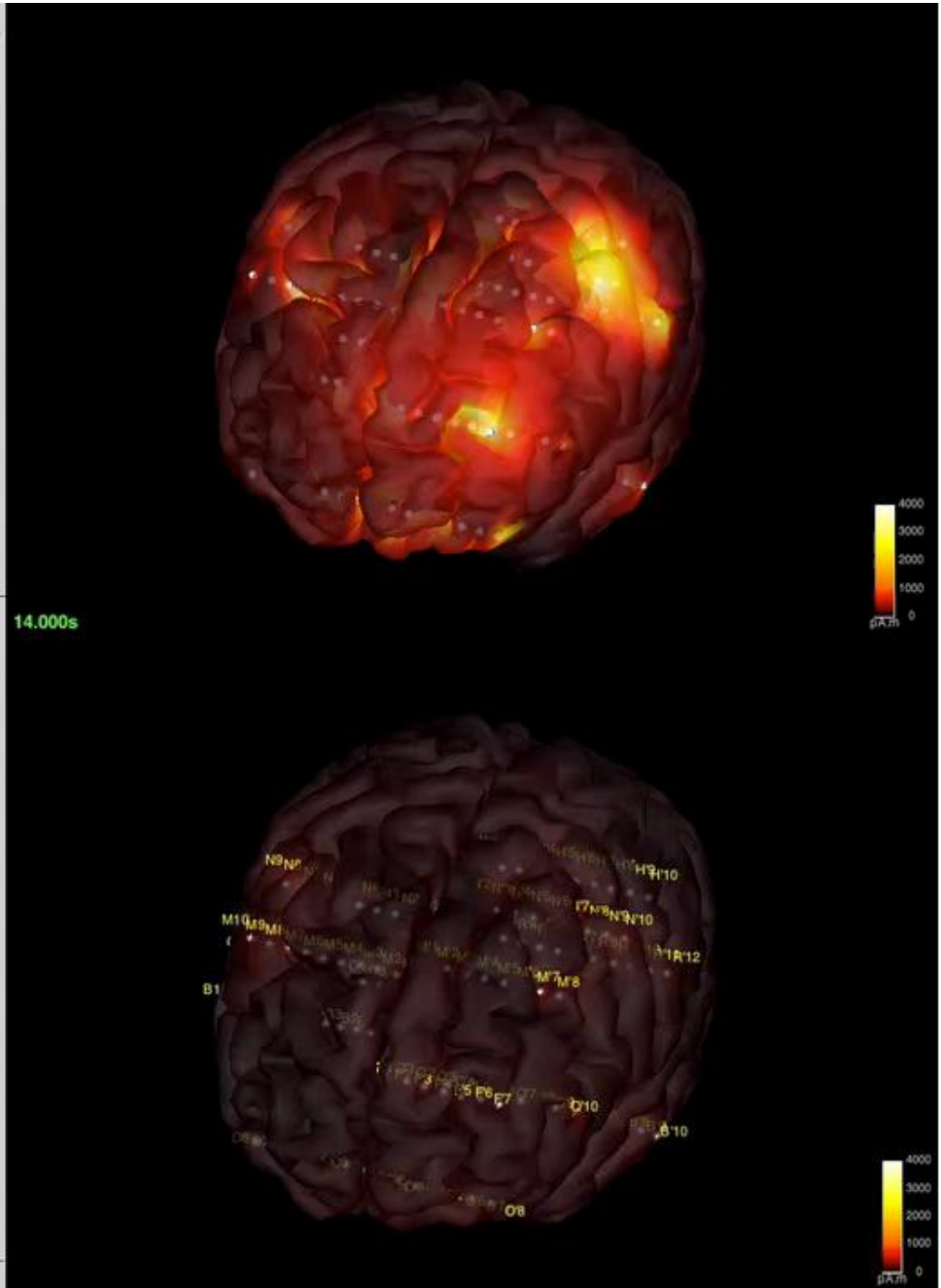
Source Imaging and Modeling

- Lead fields must be inspected for consistency
- With lead fields approved, minimum norm and its standardizations (sLORETA, dSPM, z-score) provide dynamic “heat maps”
- With good coverage (interpolation), some sources can be localized – dipole models

SZ - 1/10 speed - 2 seconds - two bands

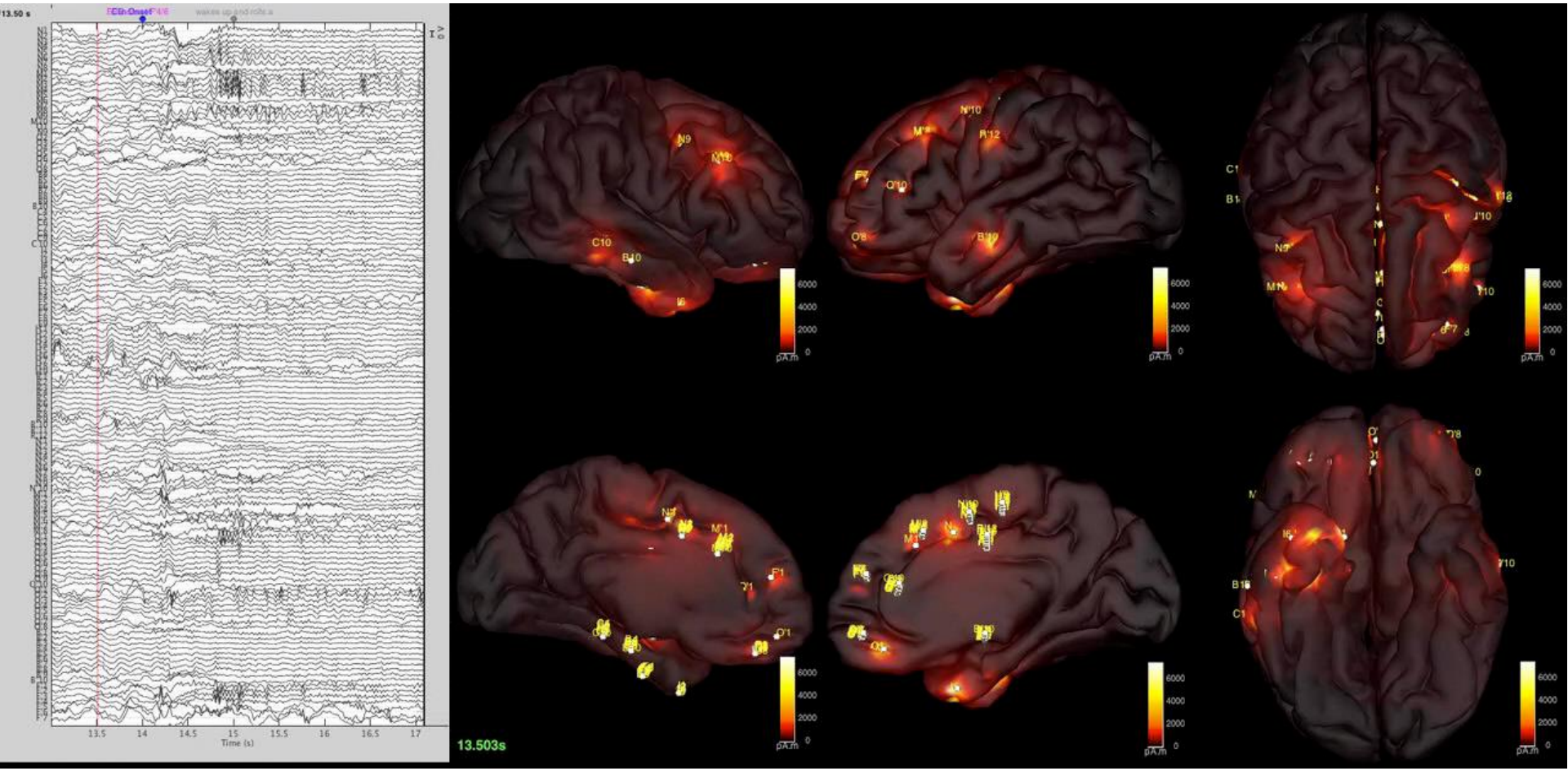






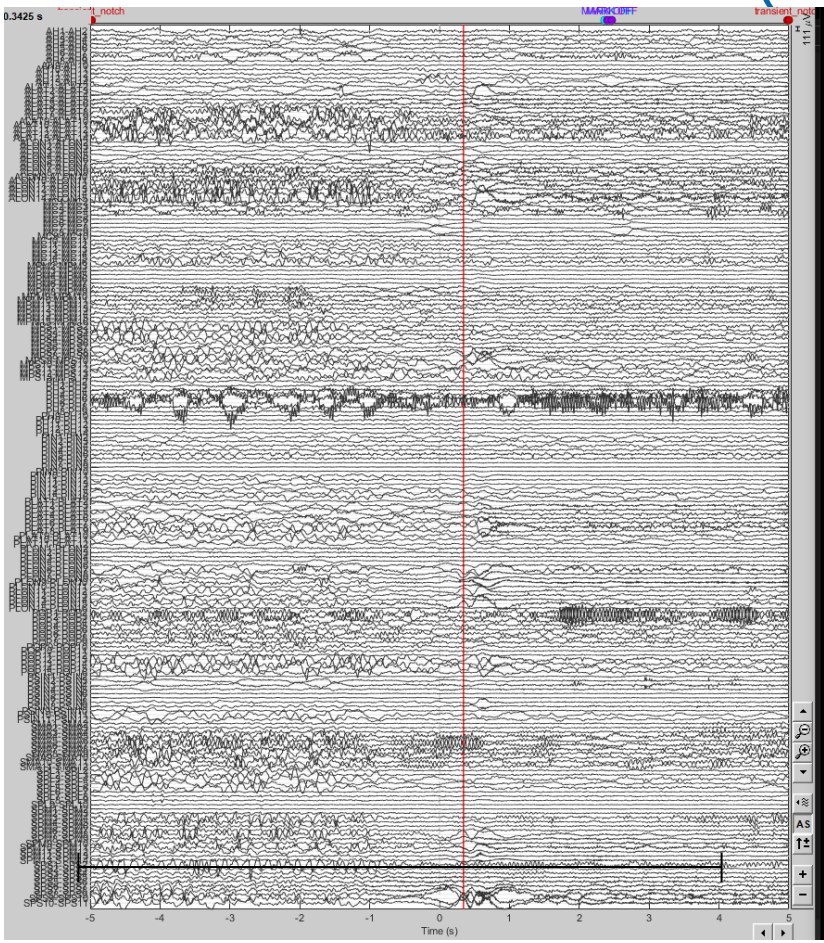
SZ Onset - Four Seconds Real-Time

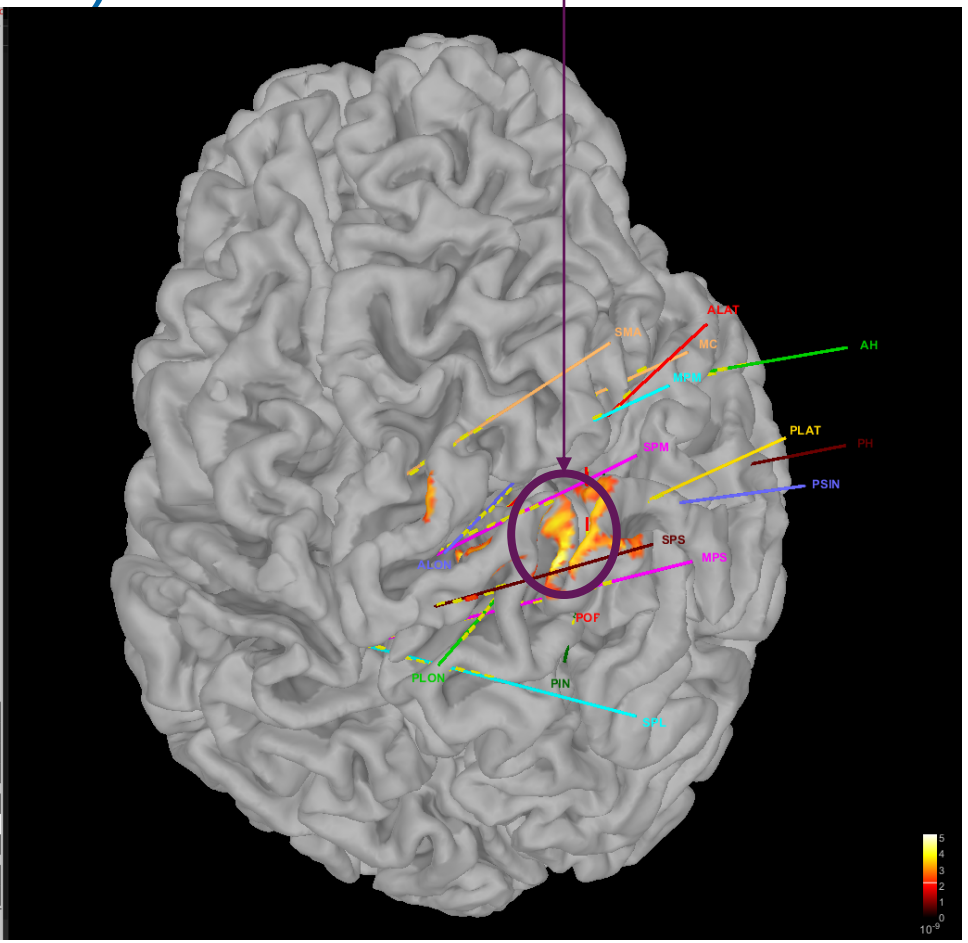
- Simultaneous different views



sLORETA on Cortex (sz 1)

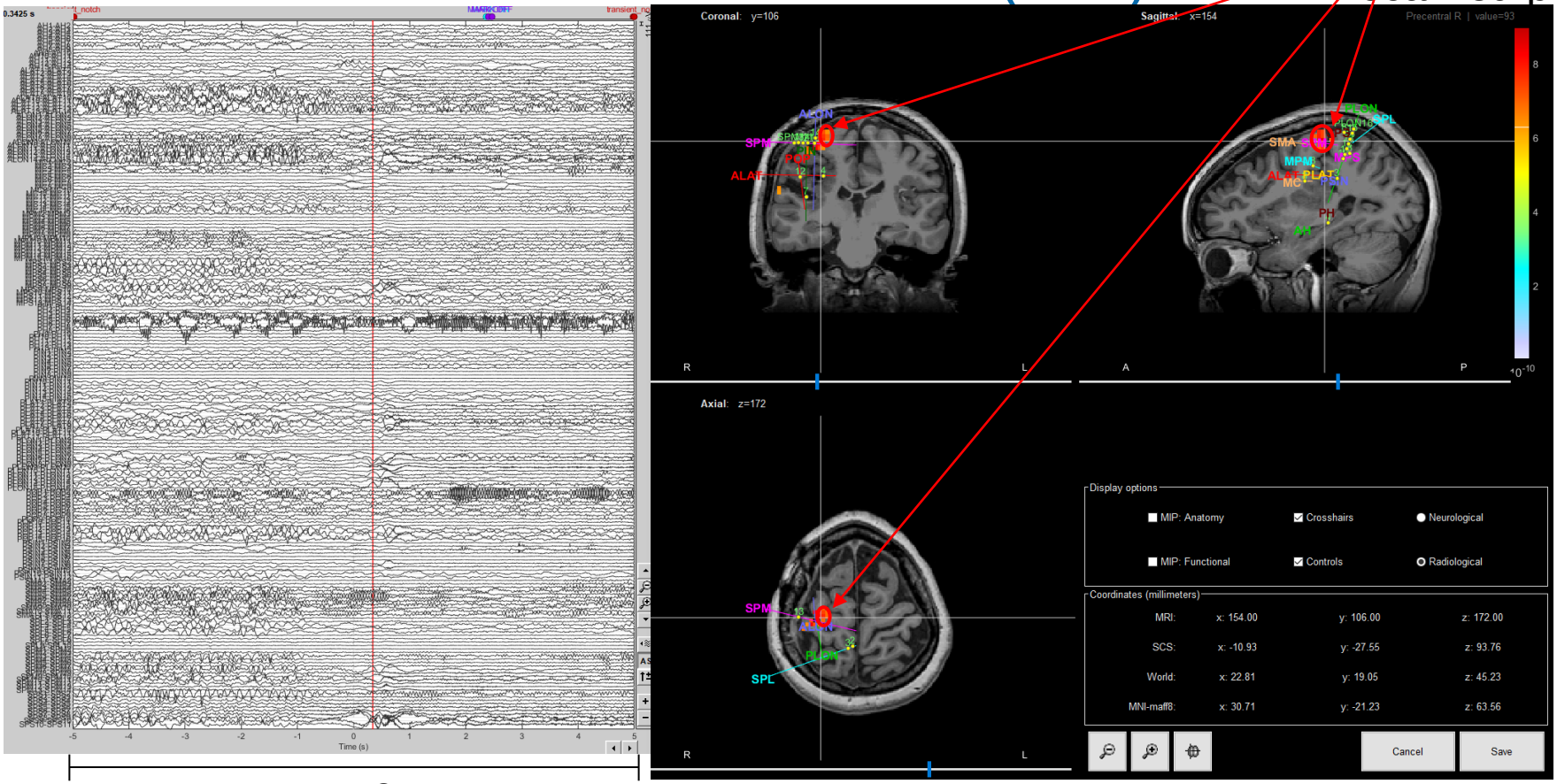
Focus of Source Localized Power





10 s

sLORETA results on MRI volume (sz 1)



(zoom) sLORETA results on MRI volume (sz 1)

Fingerprint from TF

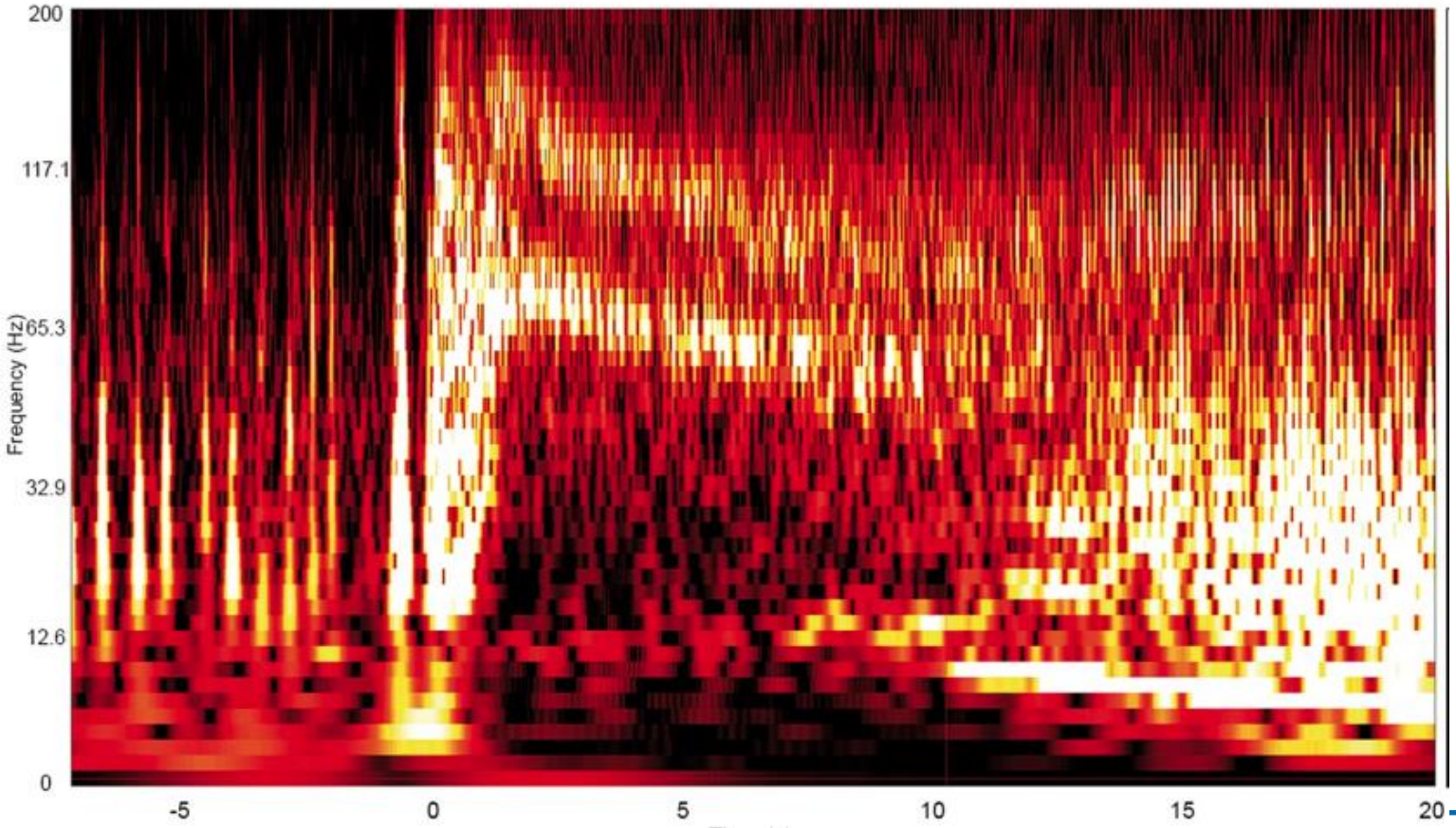
SENSOR LEVEL PROCESSING

JOURNAL ARTICLE

A fingerprint of the epileptogenic zone in human epilepsies

Olesya Grinenko, Jian Li, John C Mosher, Irene Z Wang, Juan C Bulacio, Jorge Gonzalez-Martinez, Dileep Nair, Imad Najm, Richard M Leahy, Patrick Chauvel
Author Notes

Brain, Volume 141, Issue 1, January 2018, Pages 117–131,
https://doi.org/10.1093/brain/awx306
Published: 20 December 2017 **Article history**



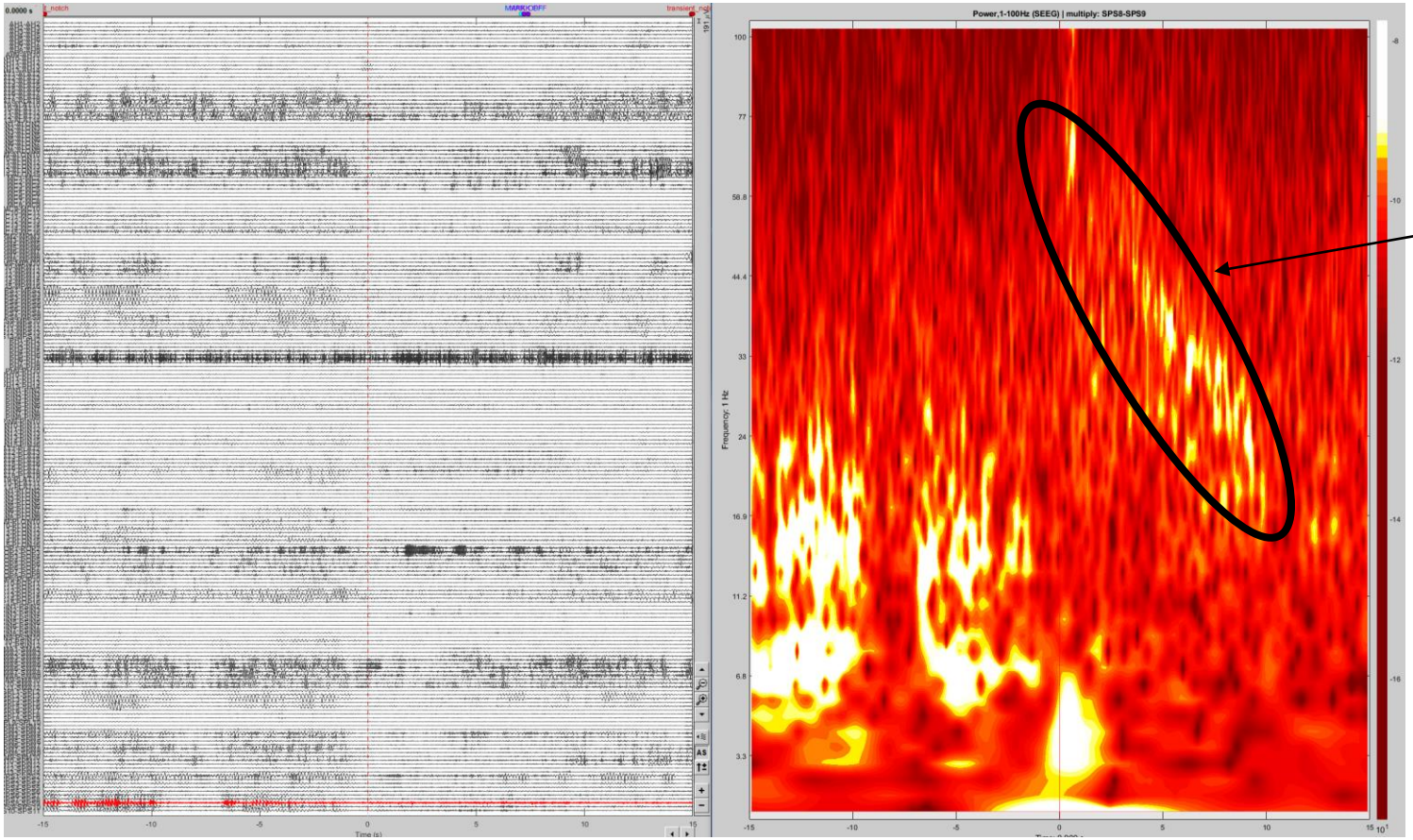
UTHealth The University of Texas Health Science Center at Houston | McGovern Medical School

From the paper

Mosher

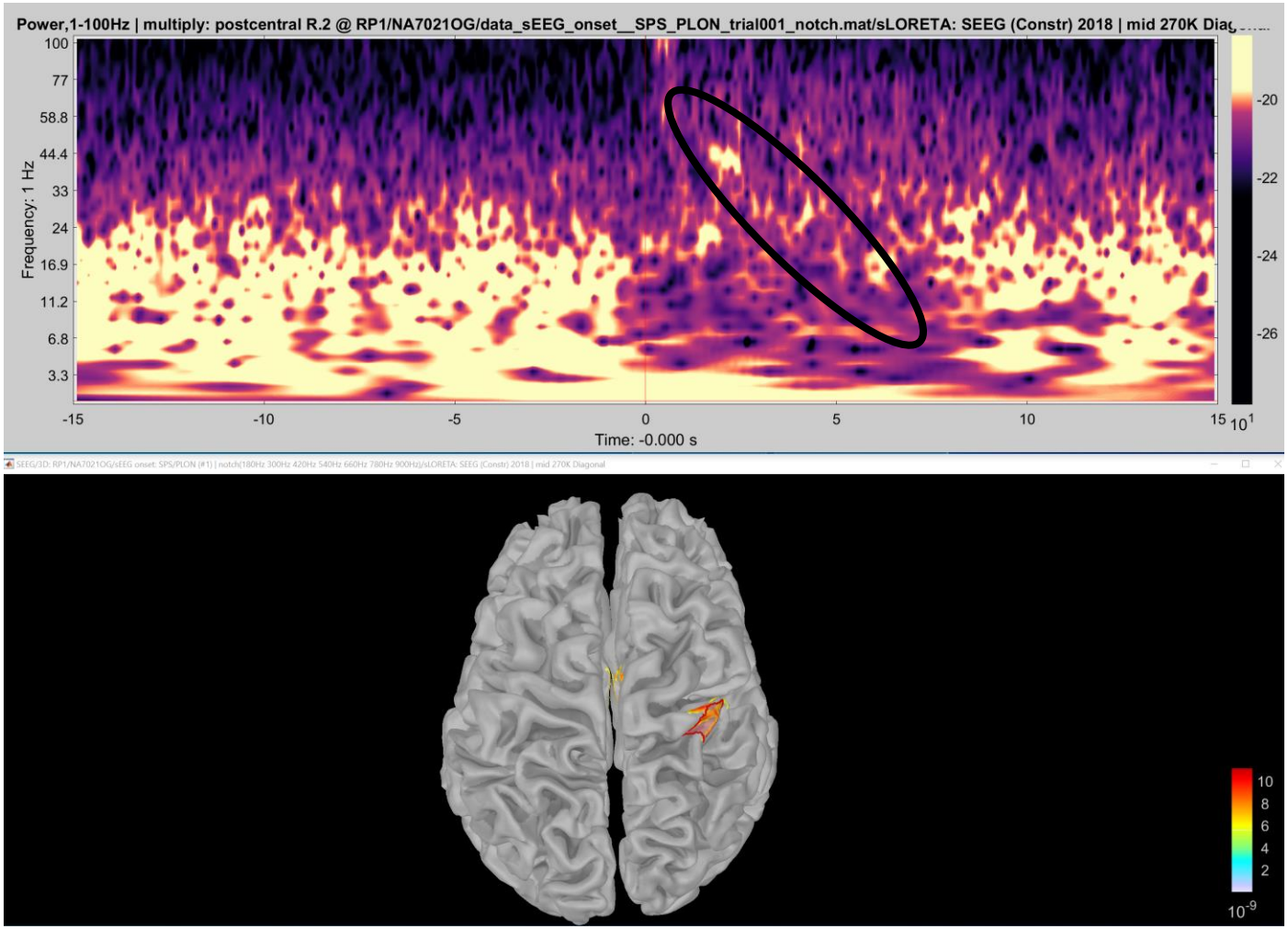
SENSOR LEVEL PROCESSING

Time-frequency decomposition in bipolar montage (sz 1)



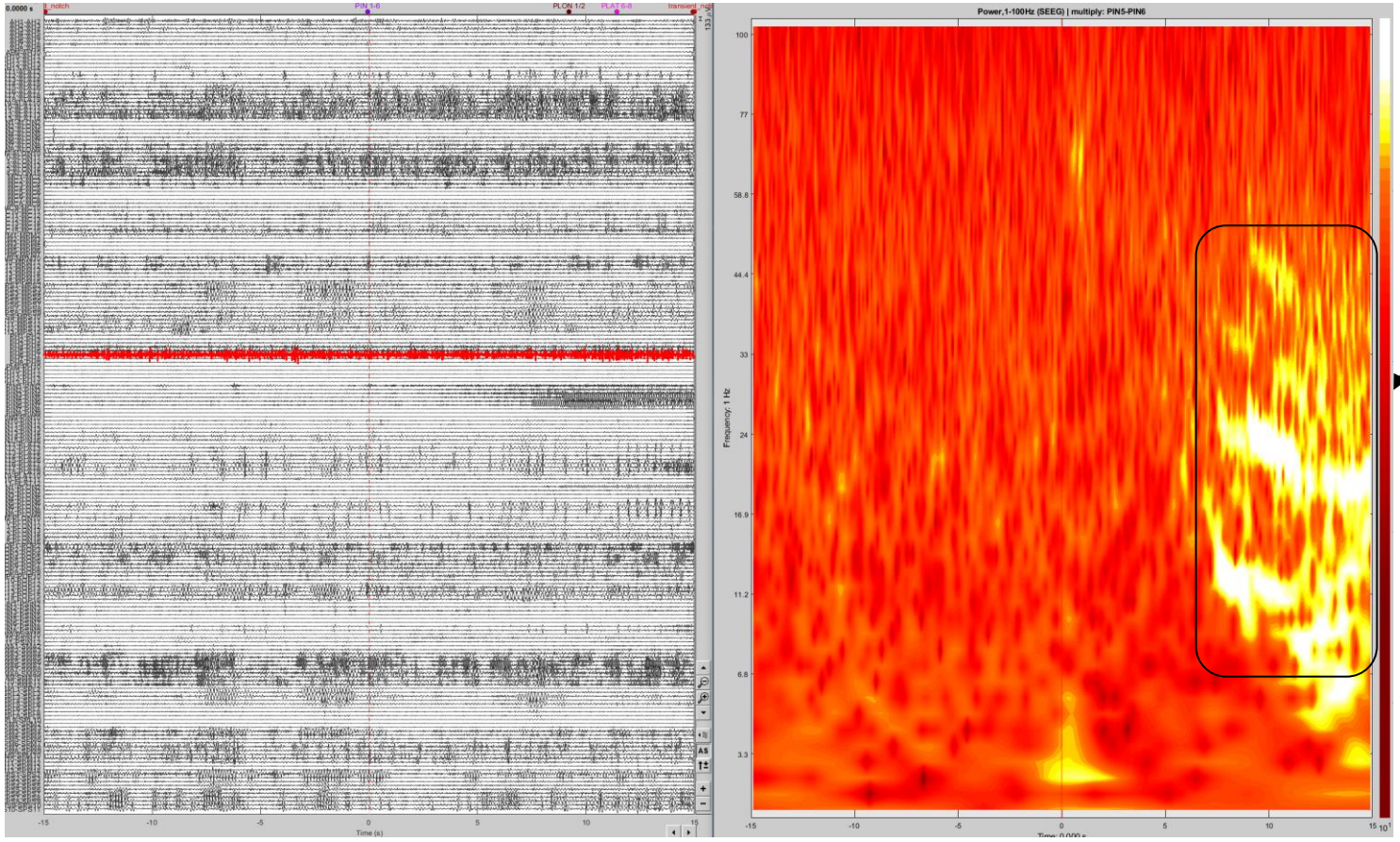
SOURCE LEVEL PROCESSING

Fingerprint on sLORETA source time-series (sz1)



Maximum PCA over the Surface Label

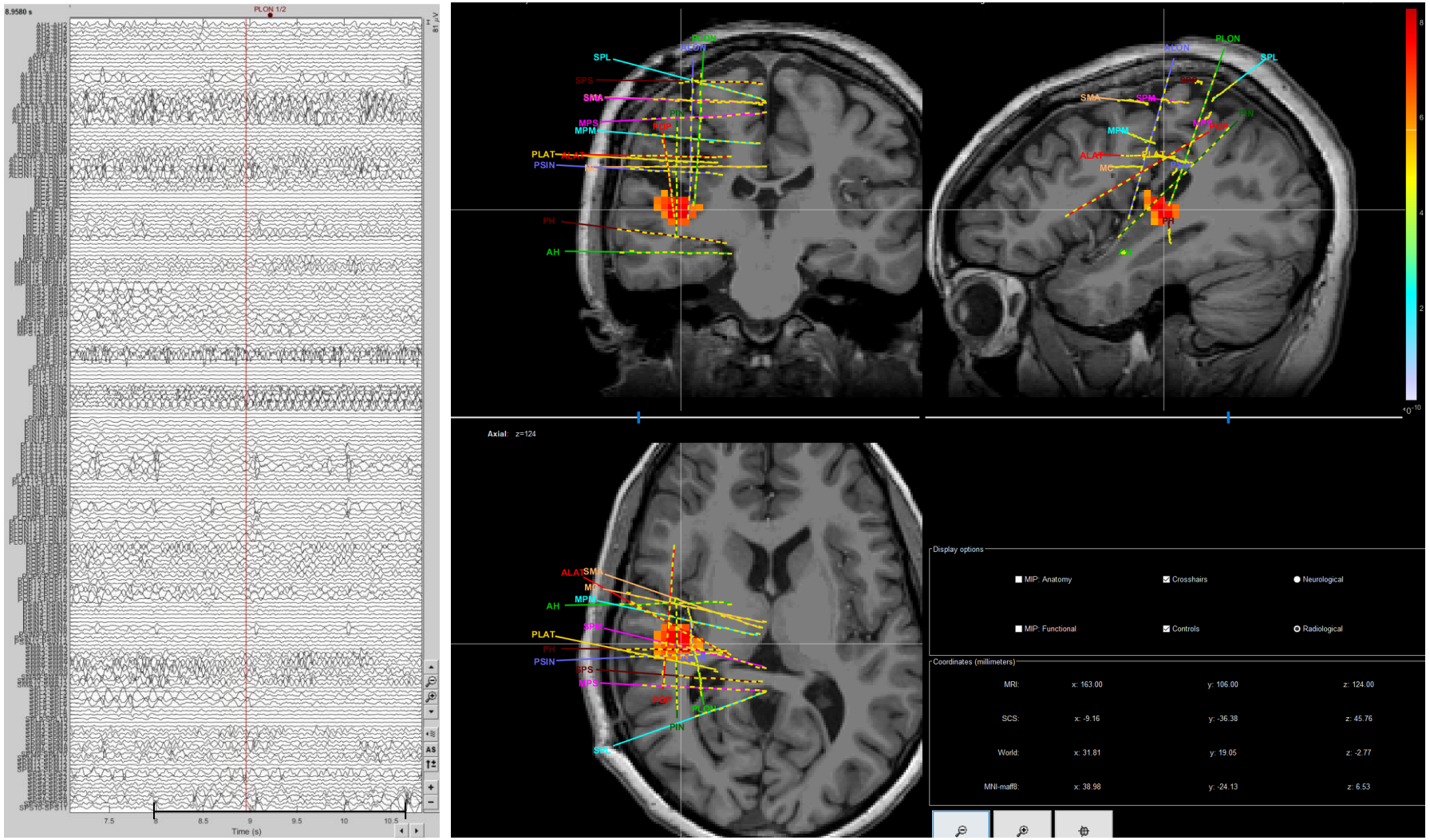
Time-frequency decomposition on PIN 5-6 (sz2)



Rhythmic activity On PIN 5-6

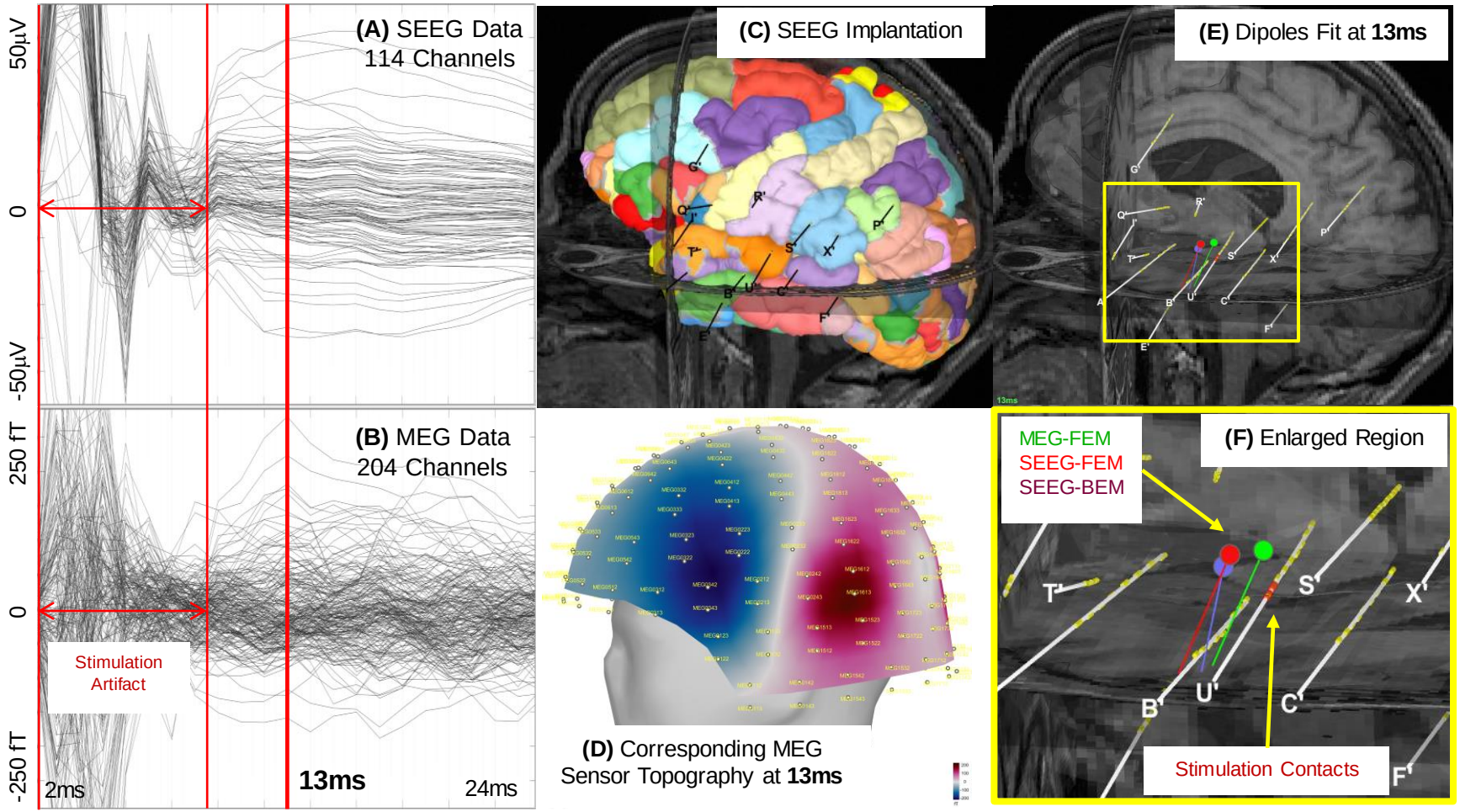
30 s

sLORETA of rhythmic activity using filter (5-55 Hz)



3 s

MEG vs SEEG, BEM vs FEM for Dipole Localization



- Bipolar current stimulation at a pair of SEEG contacts produces focal early stimulus artifact and later propagating evoked response, here recorded simultaneously in (A) SEEG and (B) MEG arrays. (C) SEEG electrode locations (black) relative to the USC brain atlas coregistered to individual anatomy. (D) MEG sensor topography of the evoked response at 13ms. (E) Brain locations of dipole models: using SEEG-BEM (blue), SEEG-FEM (red) and MEG-FEM (green). (F) Enlarged view.

Summarizing

- Lead field models under test range from the simple sphere, overlapping spheres, boundary elements, and finite elements.
- OpenMEEG and DuneNEURO easily interfaced from within Brainstorm
- Visualization and pruning very important due to sources and sensors lying in the same space.
- Min norm “heat maps” are particularly useful in SEEG, showing dynamics effectively
- Source imaging via sLORETA standardization of the min norm effective in coming “off” the contacts and into the volume
- Source modeling such as current dipoles possible when coverage is adequate