

Localisation de sources Réseaux Avenirs des techniques

Denis Schwartz

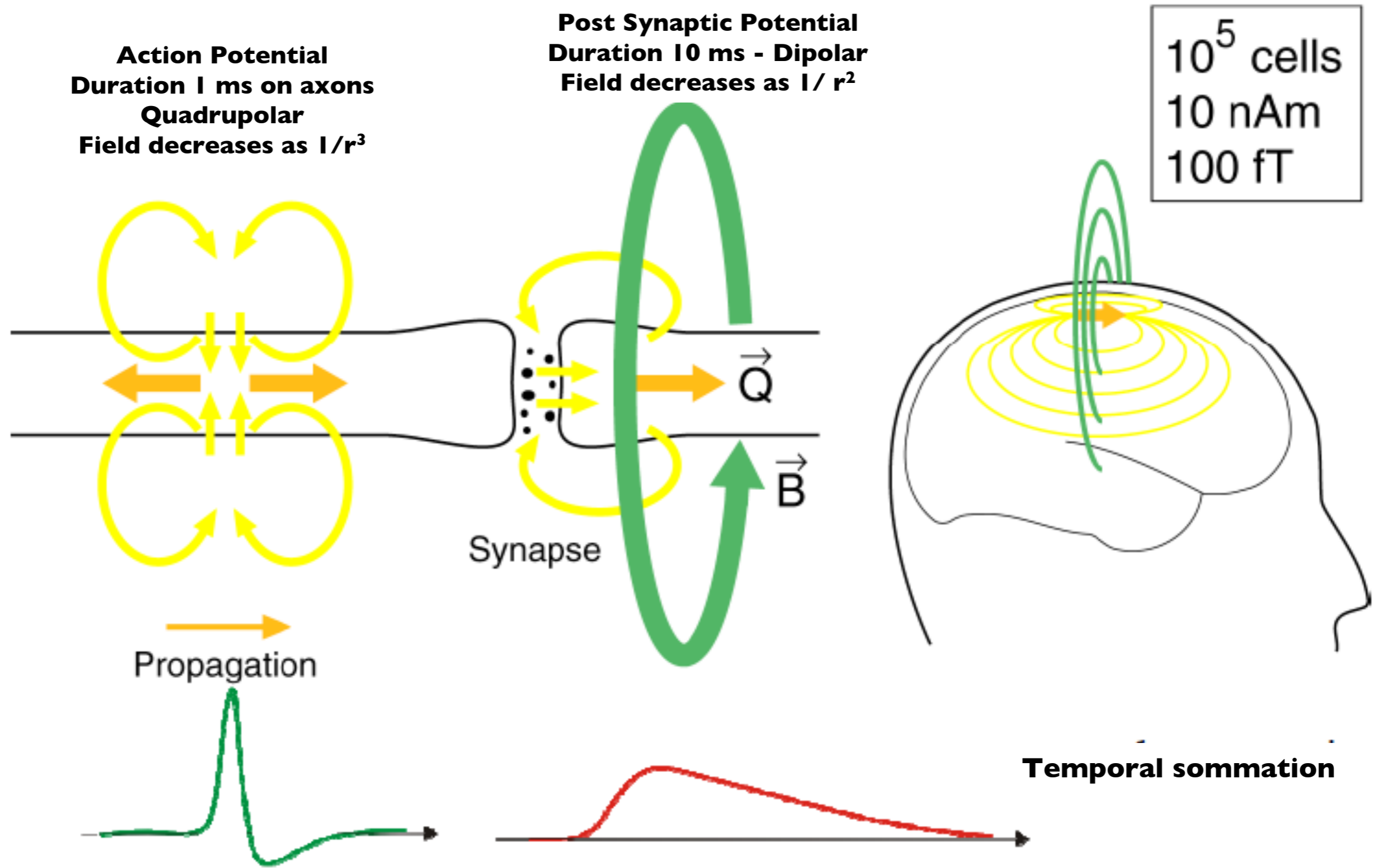
CERMEP



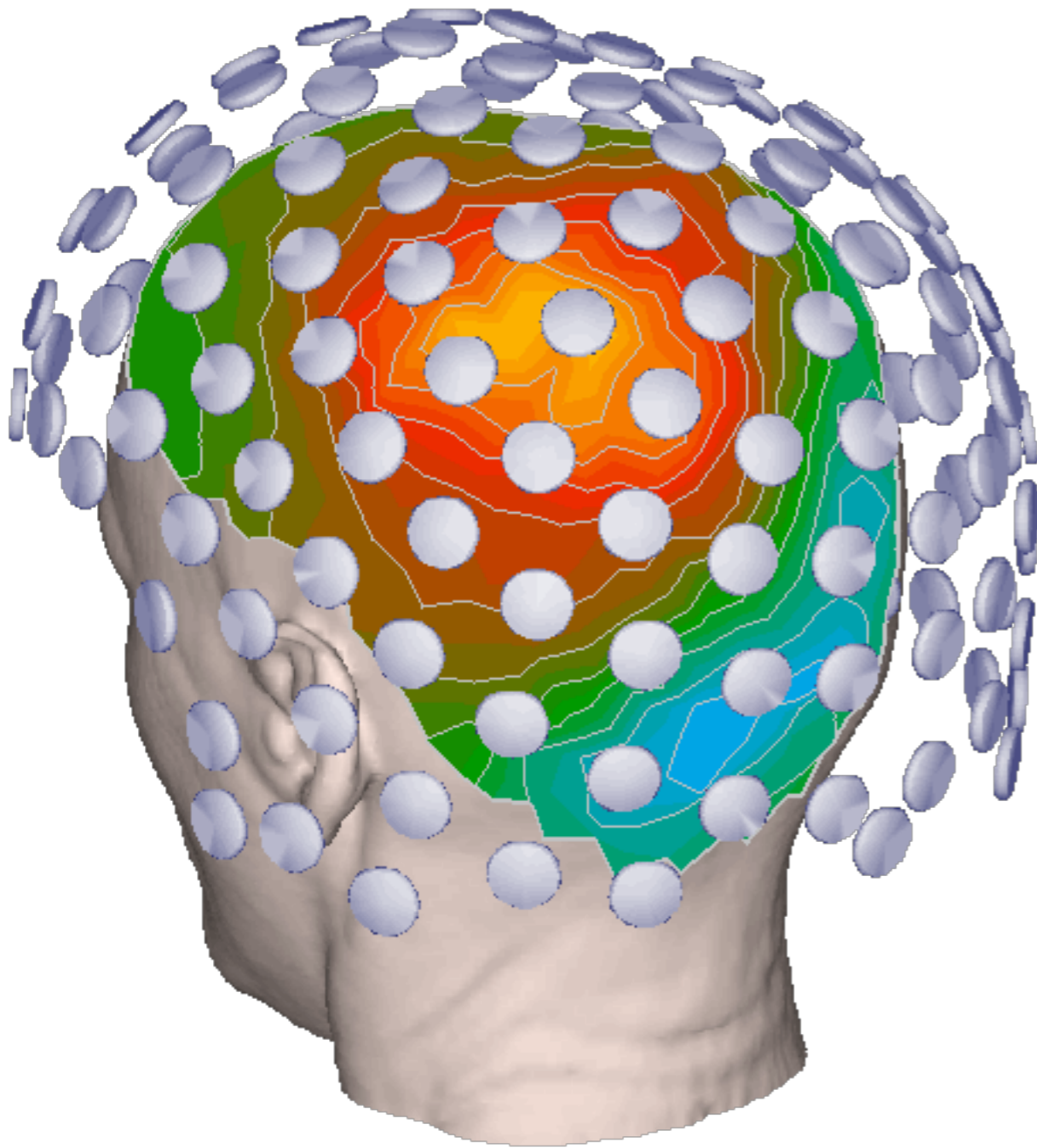
Inserm

Institut national
de la santé et de la recherche médicale

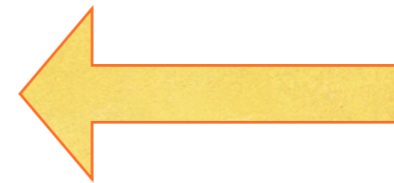
Rappels



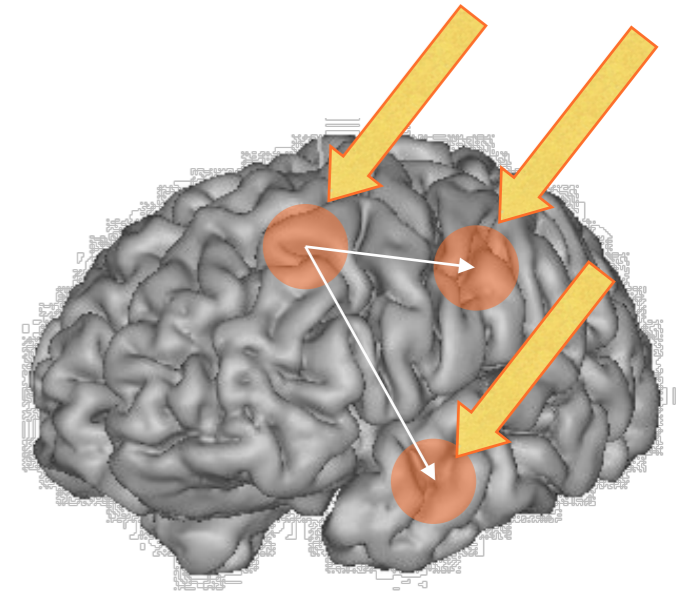
Localisation et problème inverse



Forward problem



Inverse problem



Where ?

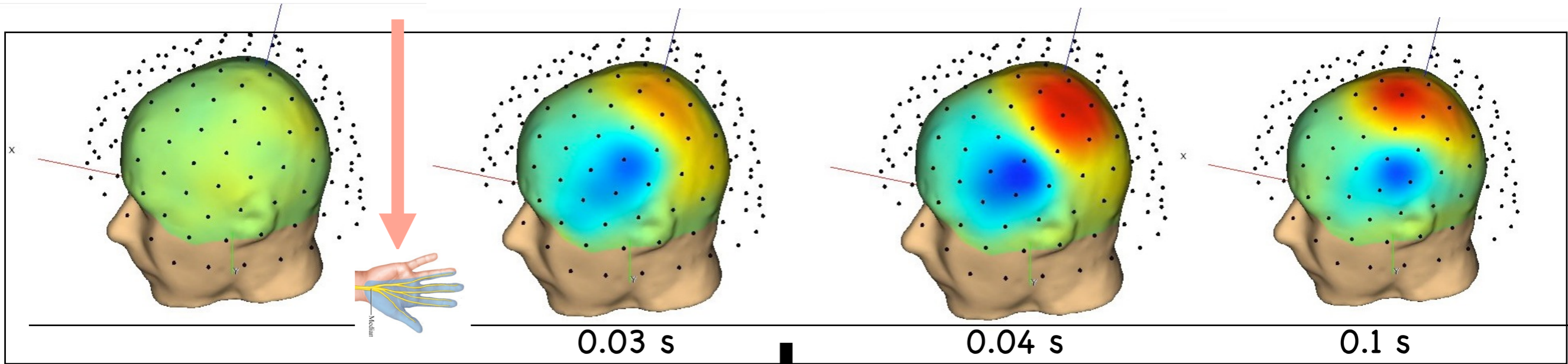
When ?

How ?

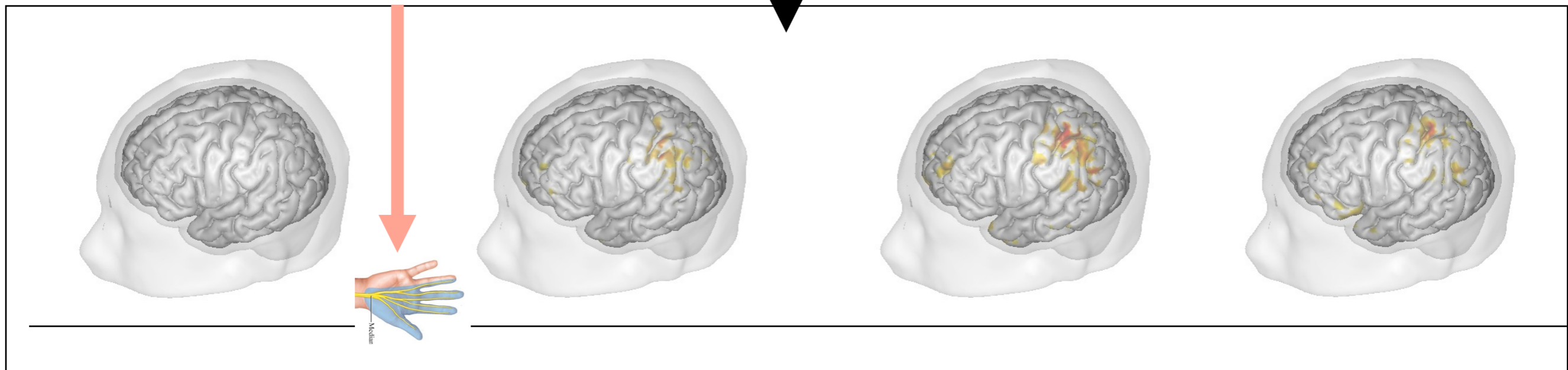
En image ...



En image



Localisation



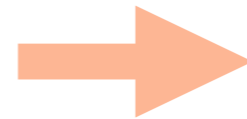
Deux étapes

- **Model** : From Neurons to Mesures [“DIRECT” problem]

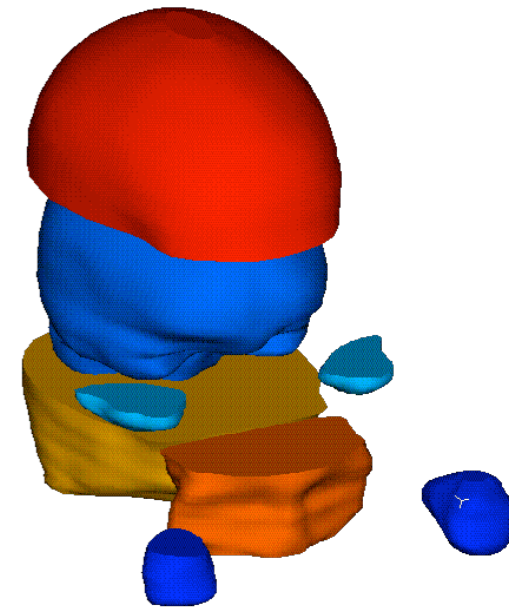
➔ Neurons [Current dipôles]

➔ Current propagation

☹ **Complex géométry**



Numeric approach
using T1 MRI



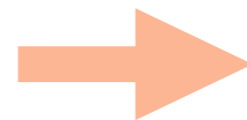
- **Estimation** : From Mesures to Neurons [“INVERSE” problem]

➔ Fit the model parameters

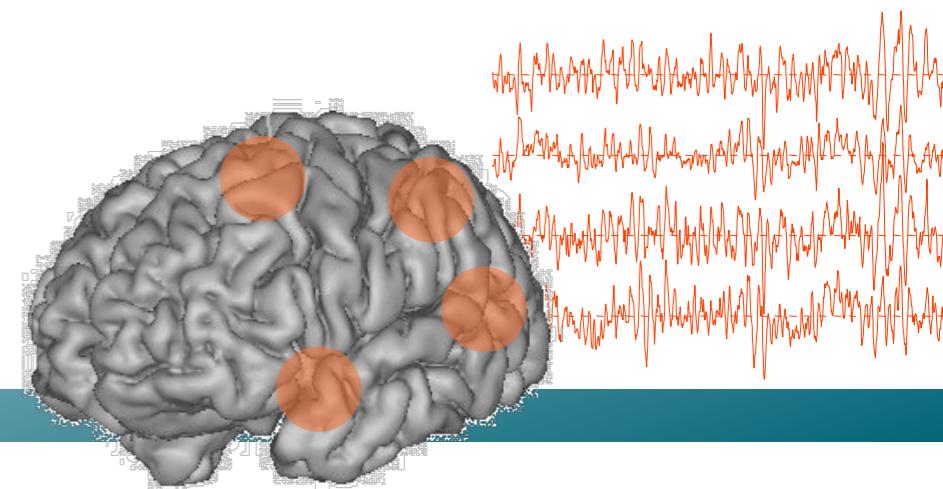
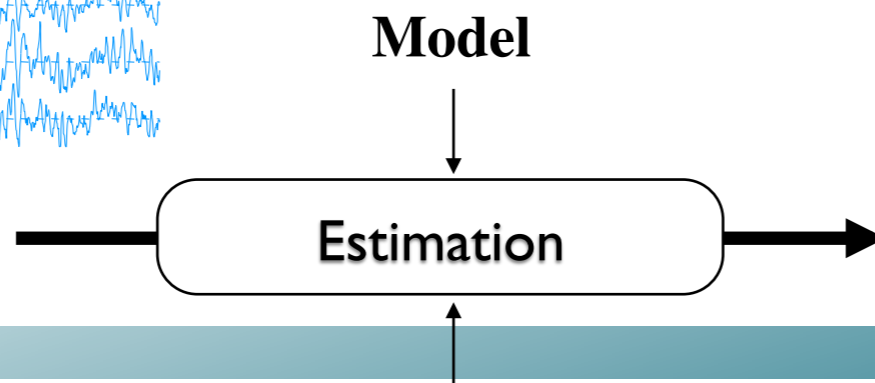
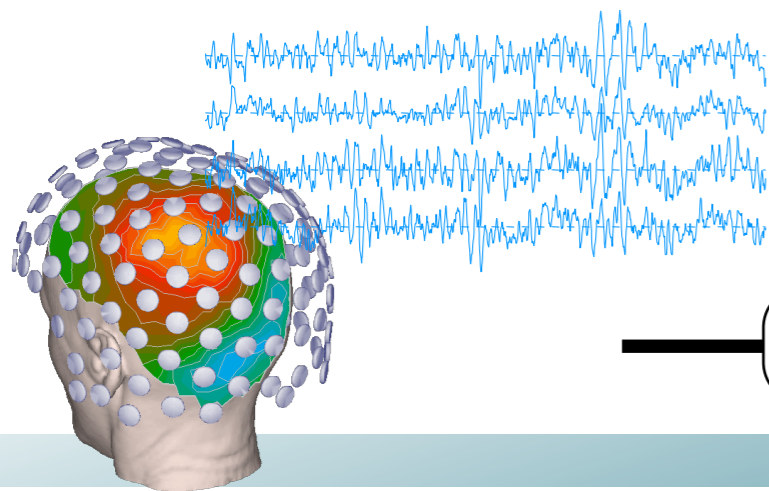
☹ **Numerical instability**

☹ **Few data**

☹ **Non unique solution**



A priori information
Regularization



Le problème direct

Two models:

How to model the electric current in a population of neurone?

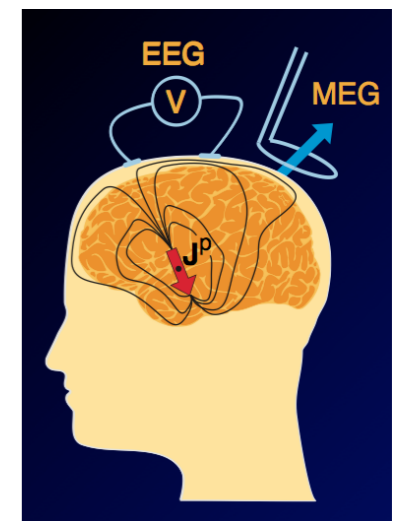
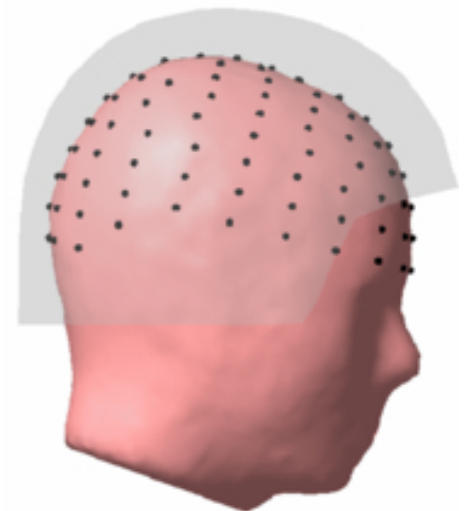
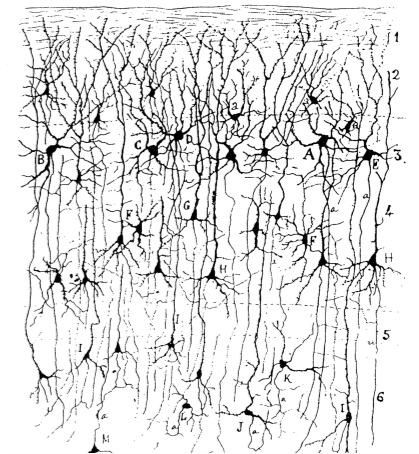
= **Sources of brain electric activity**

Parameters : **position, orientation & amplitude** along the time

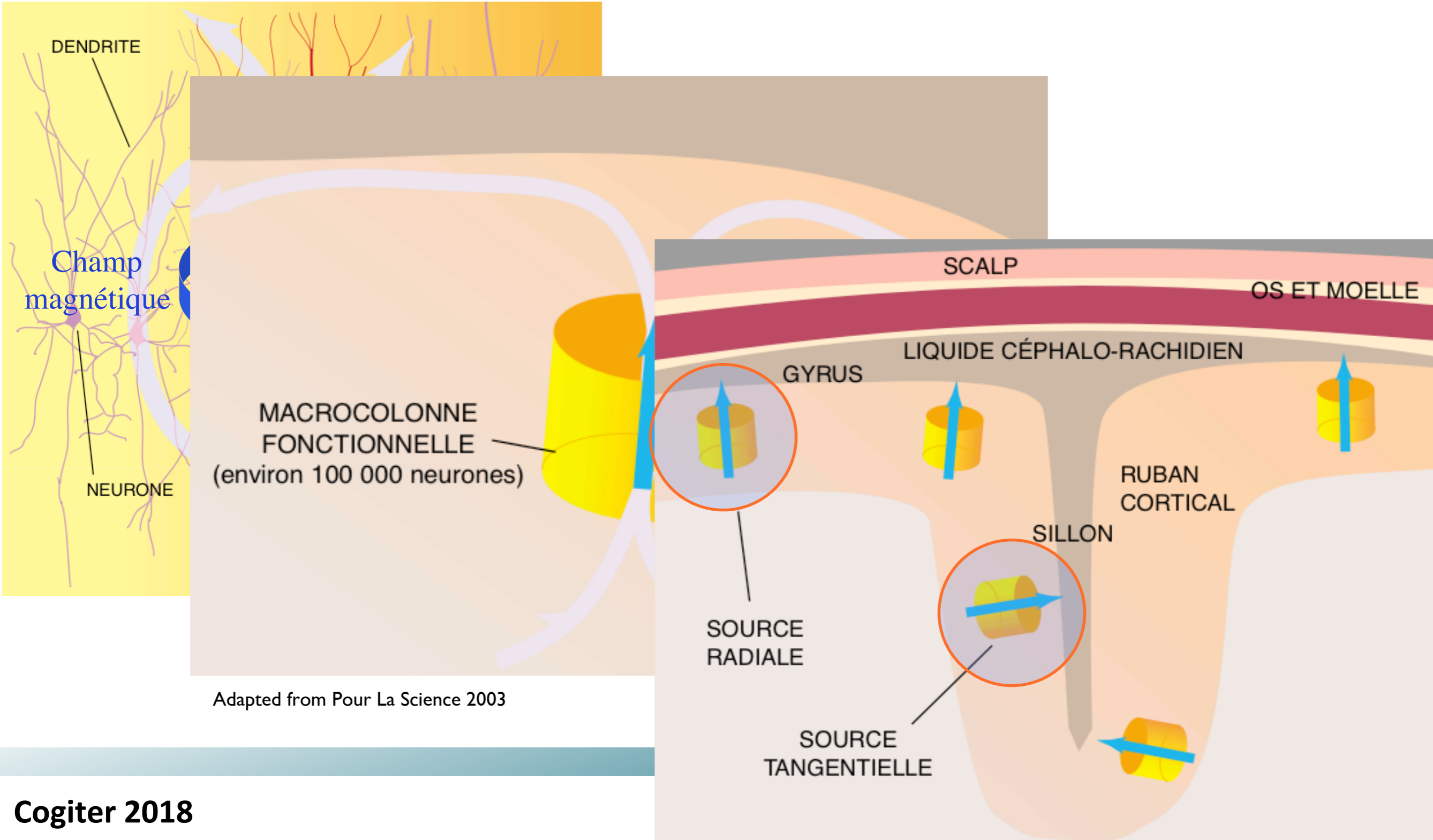
How the currents generated by the sources affect the sensors?

= **Geometrical model of the head**

Parameters : **geometry, conductivity & localisation with respect to the sensors**

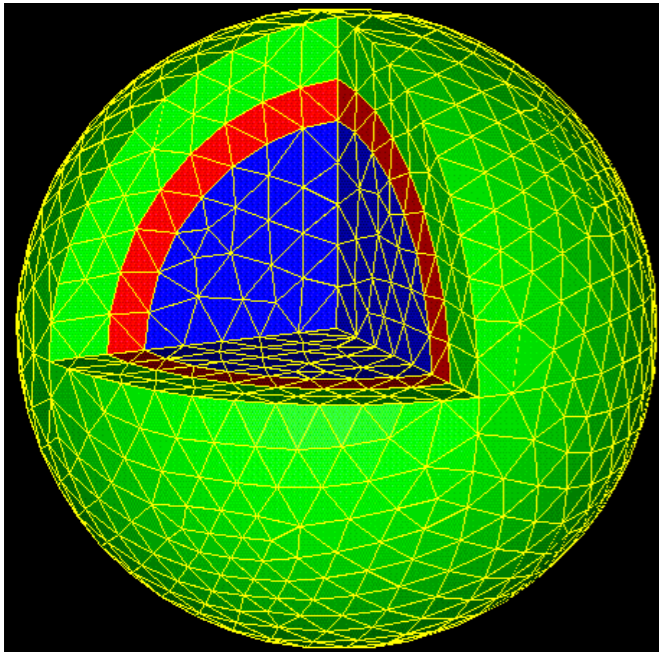


Modèle de sources



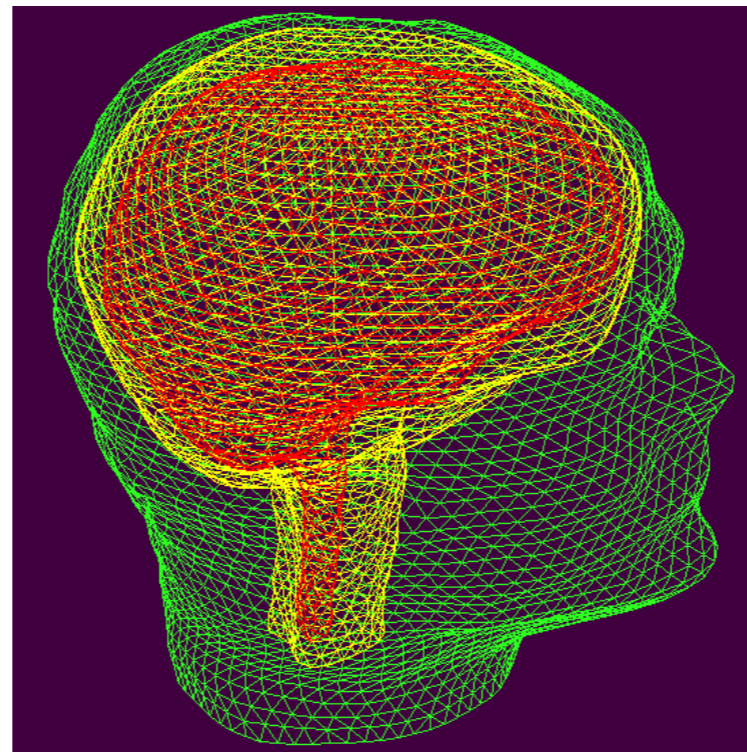
Le modèle géométrique

Spherical Model



Analytic solution for B & V

Realistic Model Homogeneous layers

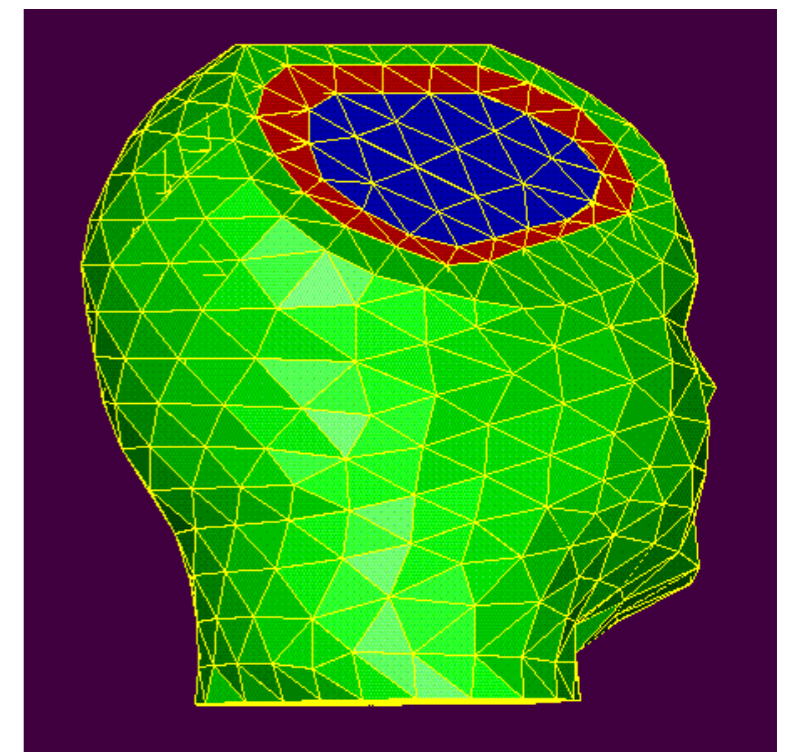


Boundaries Integrals

Homogeneous and isotrop layers

Surface meshes (brain, skull & scalp)

Realistic Model inhomogeneous



Finite elements and differences

Inhomogeneous and non isotrop conductivity

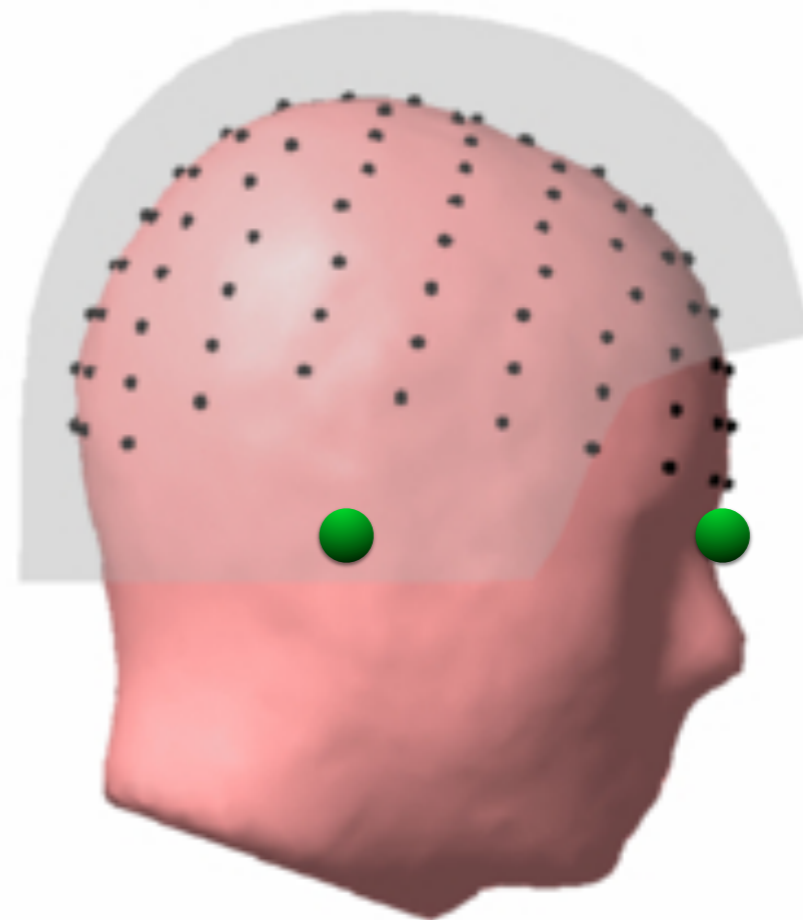
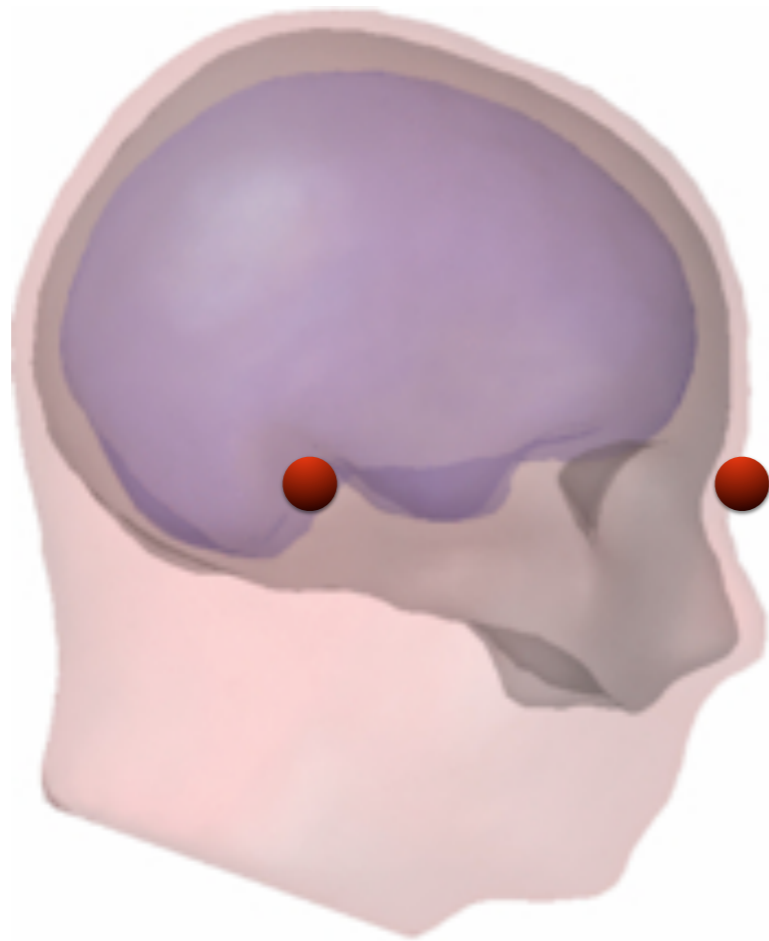
3D meshes

Recalage MEG + IRM

IRM

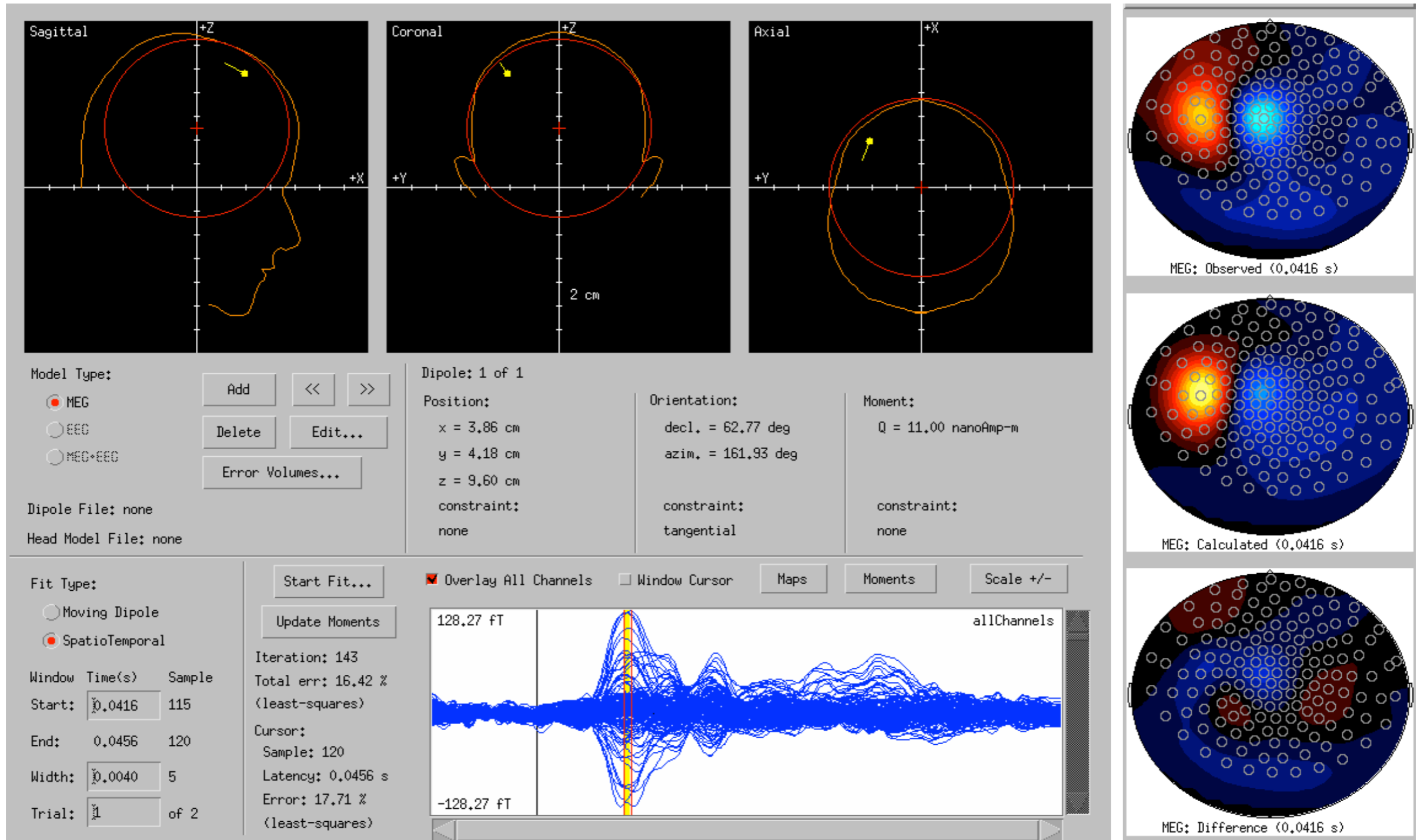


MEG/EEG Sensors



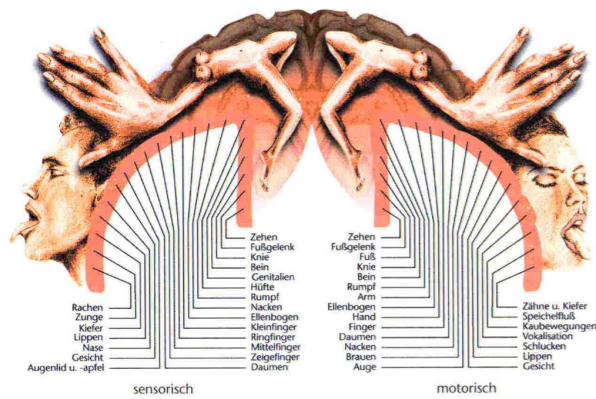
Translation + Rotation

Exemple

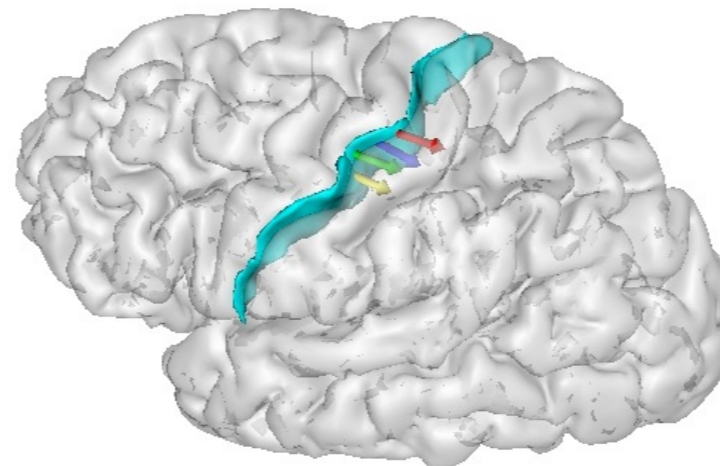
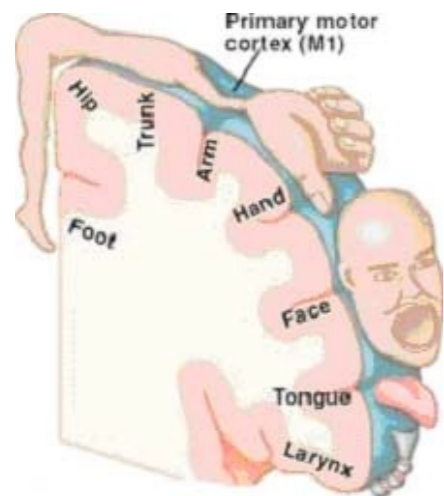
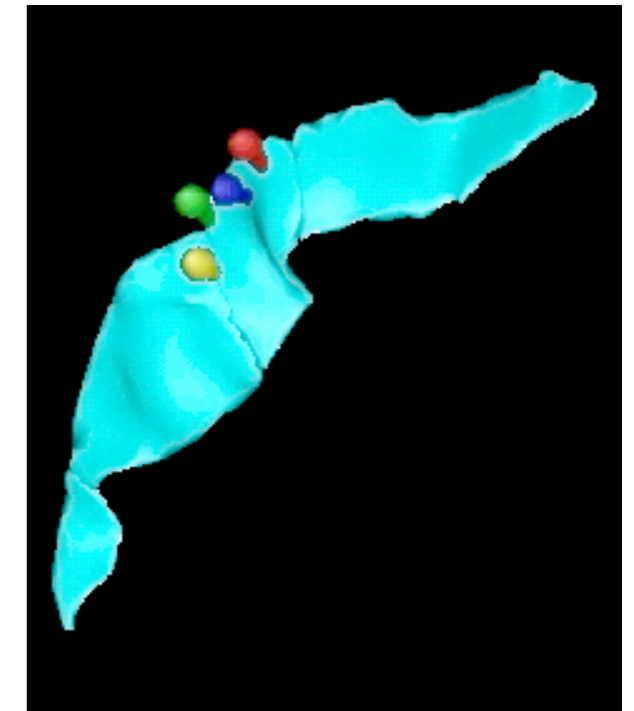
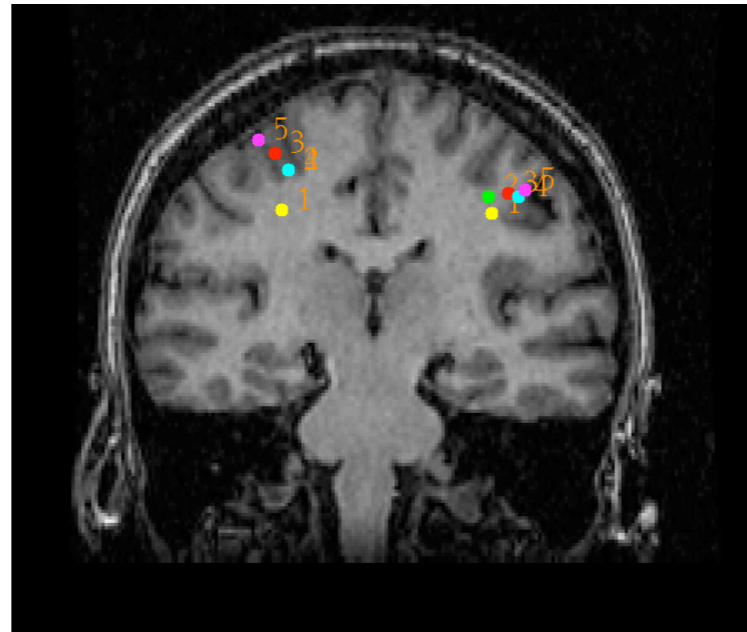


Somatotopie

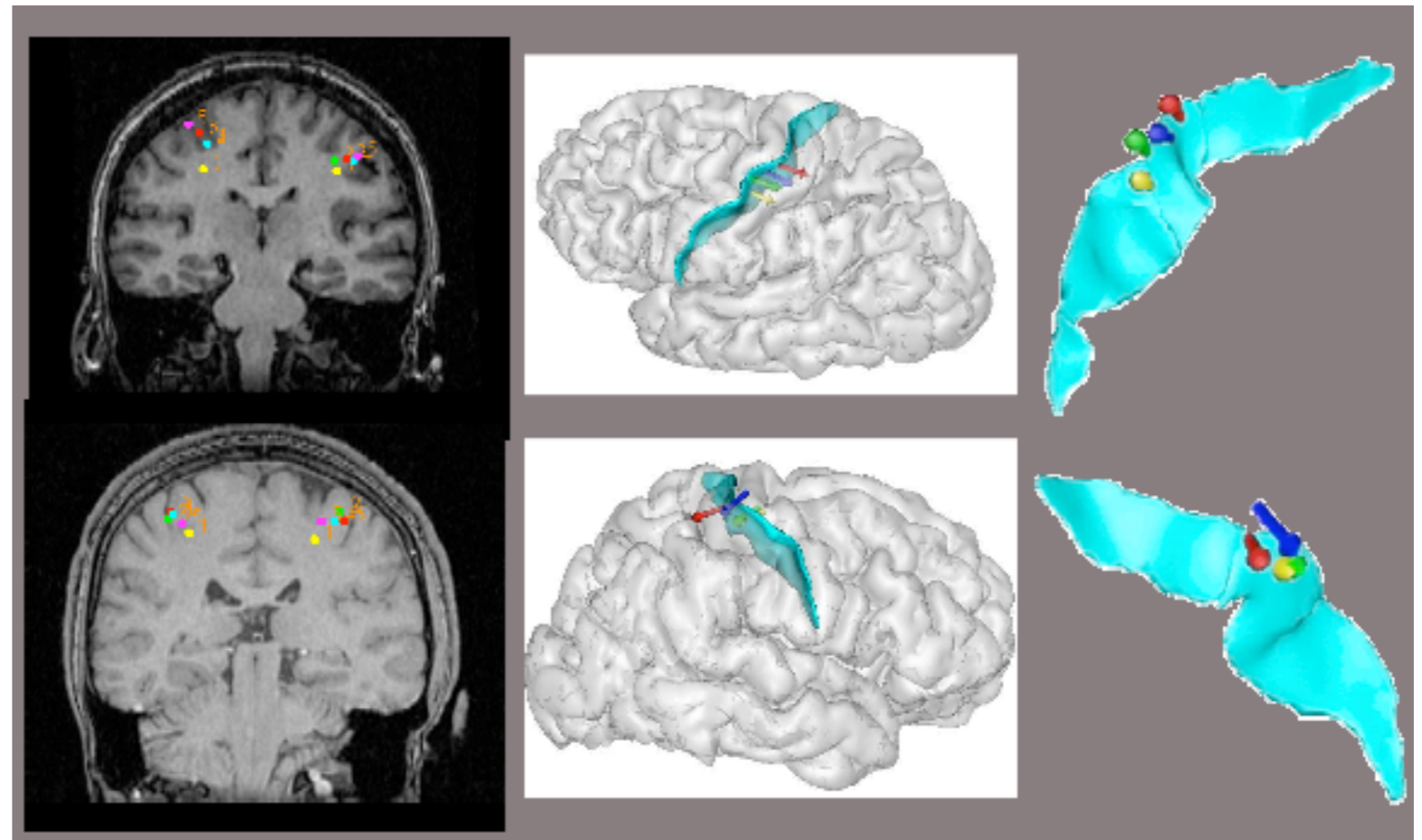
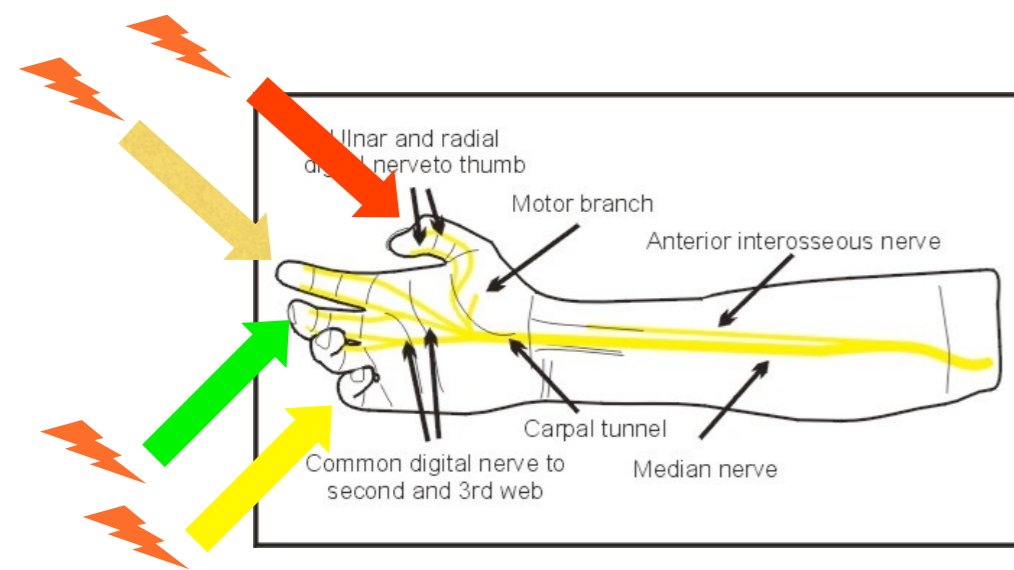
Fingers somatotopy



Projektionsfelder auf der Großhirnrinde (Homunculus)



Dystonie



MEUNIER S., GARNERO L., DUCORPS A., MAZIERES L., LEHERICY S., TEZENAS DU MONTCEL S., RENAULT B., VIDAILHET M.(2001) **Human brain mapping in dystonia reveals at once endophenotype and adaptative reorganization**, *Annals of Neurology*, 50 :521-527.

MEUNIER S., LEHERECY S., GARNERO L., VIDAILHET M. (2003) **Dystonia : Lessons from Brain Mapping** . *Neuroscientist*, 9, 1, 76-81

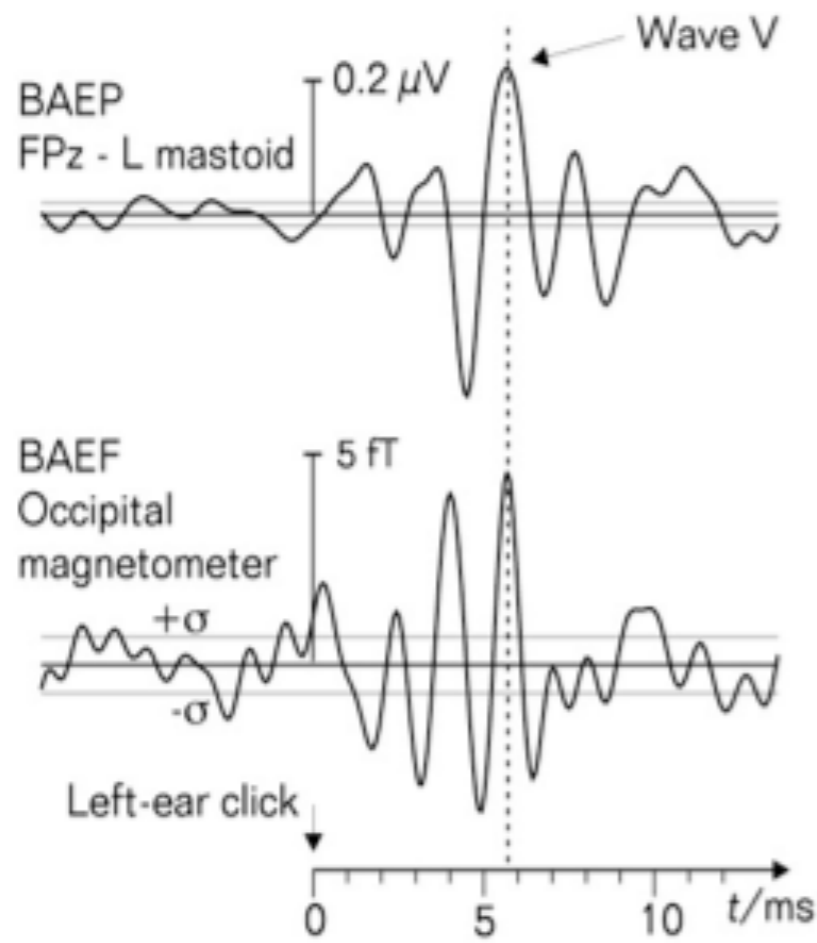
Un exemple profond ...

STIMULUS:

0.6-ms auditory clicks to left ear
111 ms ISI, 15000 epochs averaged

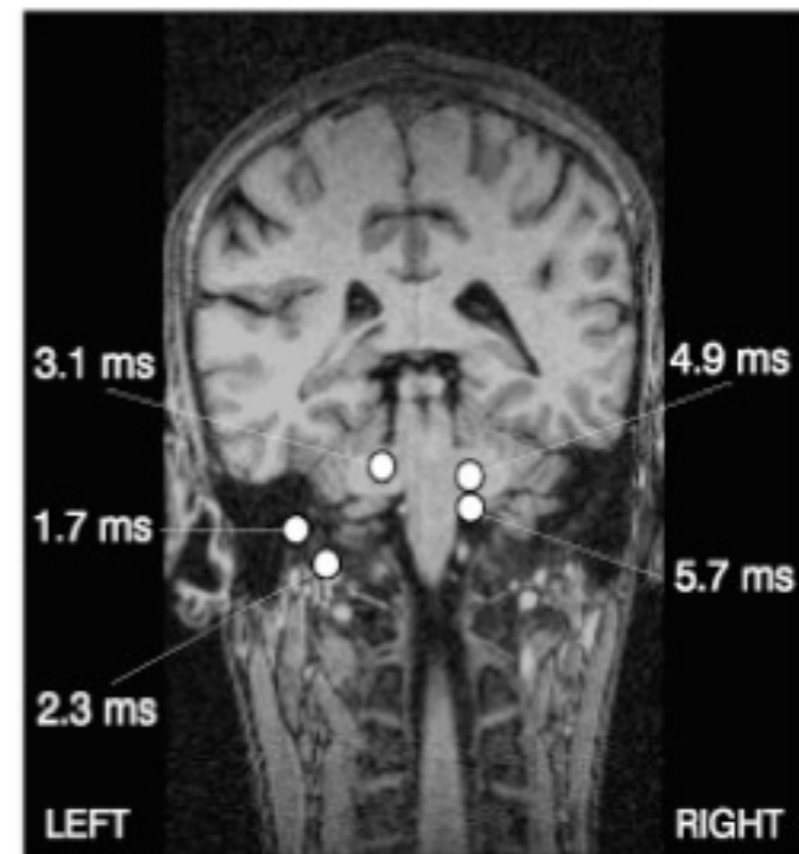
RESPONSES:

Shown with pass-band 160 – 900 Hz



ANALYSIS:

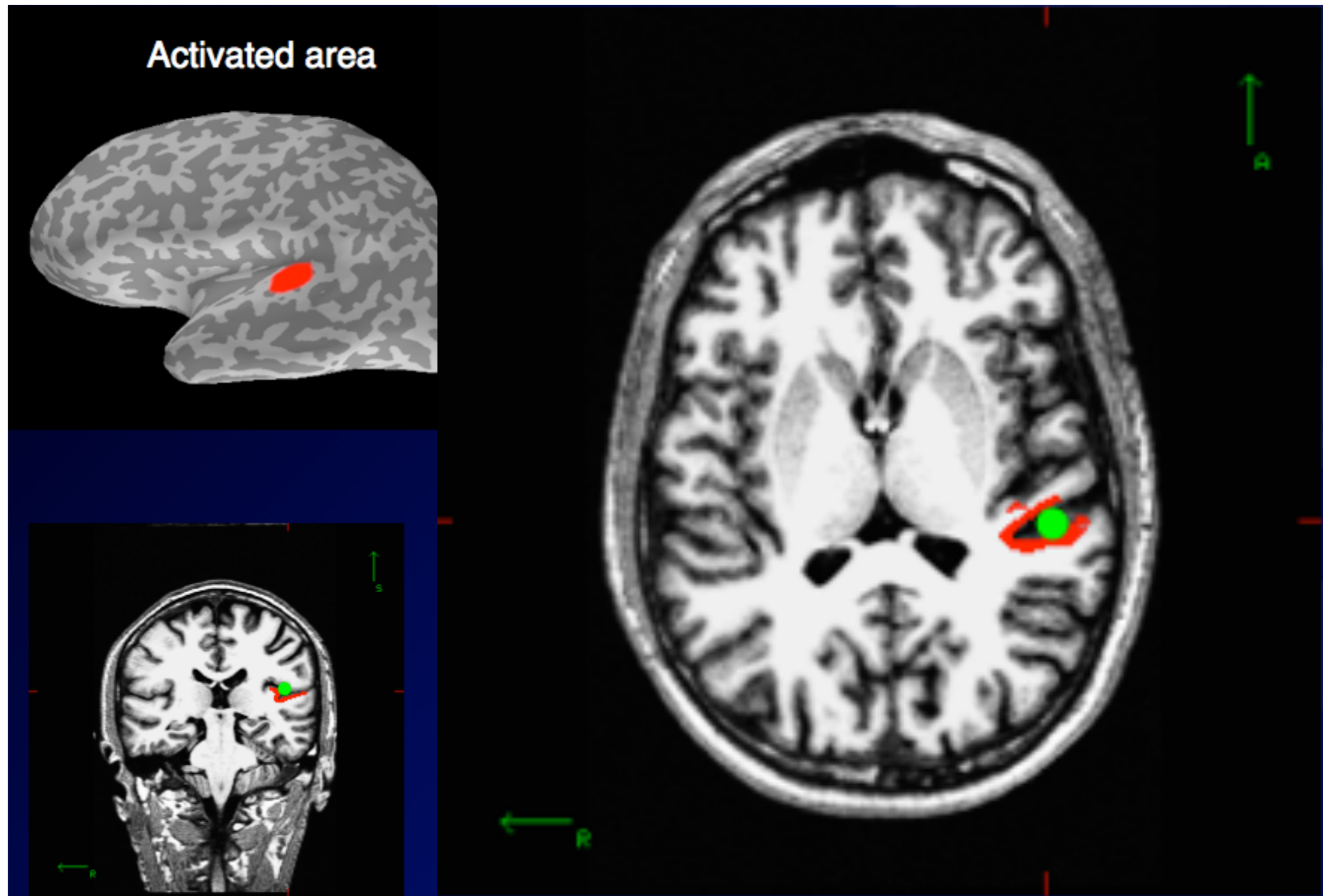
- individual BEM models
- equivalent current dipoles



NOTE: All sources visualized on a single MRI slice.

Parkkonen et al. 2002

Les sources étendues ?



Approches Imagerie

Baillet et al 2001 - IEEE Biomed

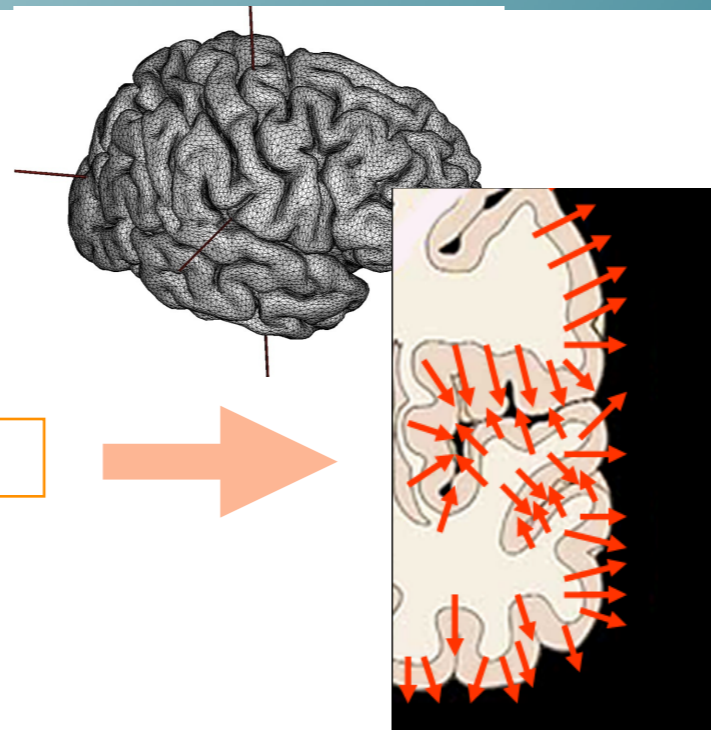
- **Mathematical model**

MEG / EEG measures

$$M = G \cdot s + n$$

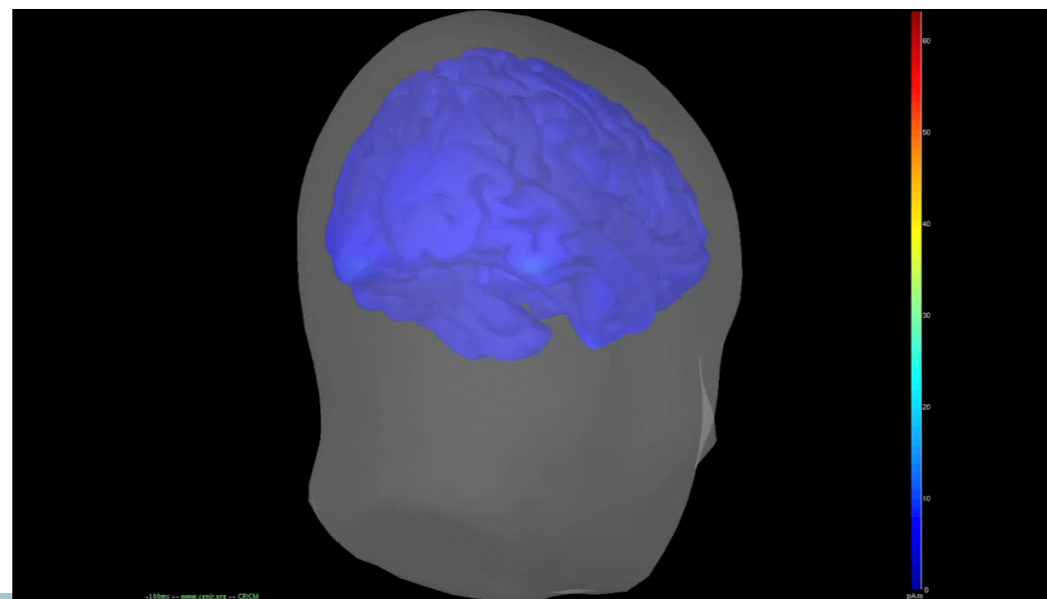
Sources activity

Direct problem



Pos. & Orient. known
Unknown : Moment
along the time

- **Inversion** : Minimum norm



Formalisation

Baillet et al 2001 - IEEE Biomed

- **Mathematical model of the data (linear!):**

$$\begin{array}{c} N_c \times N_t \\ \text{MEG / EEG measures} \\ \mathbf{M} = \mathbf{G} \cdot \mathbf{S} + \mathbf{n} \quad \text{Noise} \\ \text{Cortical activity} \\ \text{Direct Problem} \\ N_c \times N_s \end{array} \quad \begin{array}{c} N_s \times N_t \\ N_s \times N_t \\ N_s \times N_t \end{array}$$

$N_c \Rightarrow$ Number of sensors

$N_t \Rightarrow$ Number of time points

$N_s \Rightarrow$ Number of sources

$\mathbf{M} \Rightarrow$ Your **known** MEG or EEG signals

$\mathbf{G} \Rightarrow$ Your **known** forward operator

$\mathbf{S} \Rightarrow$ Your **unknown** cortical currents

$\mathbf{N} \Rightarrow$ **Known** zero-mean additive noise

- ★ \mathbf{G} explains the magnetic field created by a source with known location & direction on each sensor
- ★ It is sufficient to know **the noise covariance matrix** which is computable from your raw data

$$\tilde{s} = \min \|\mathbf{M} - \mathbf{G}\mathbf{s}\|^2 + f(\mathbf{s})^2 \quad \longrightarrow \quad \tilde{\mathbf{s}} = \min \|\mathbf{M} - \mathbf{G}\mathbf{s}\|^2 + \lambda \|\mathbf{s}^2\|$$

Calcul de l'opérateur inverse

$$\tilde{s} = \min \|M - Gs\|^2 + \lambda \|s\|^2$$

$$\underset{Ns \times Nt}{\tilde{S}} = \underset{Ns \times Nc}{W} \cdot \underset{Nc \times Nt}{M}$$

$$W = \underset{\text{Signal Covariance}}{R} G^T \cdot \left(\underset{\text{Noise Covariance}}{G R G^T + \lambda C} \right)^{-1}$$

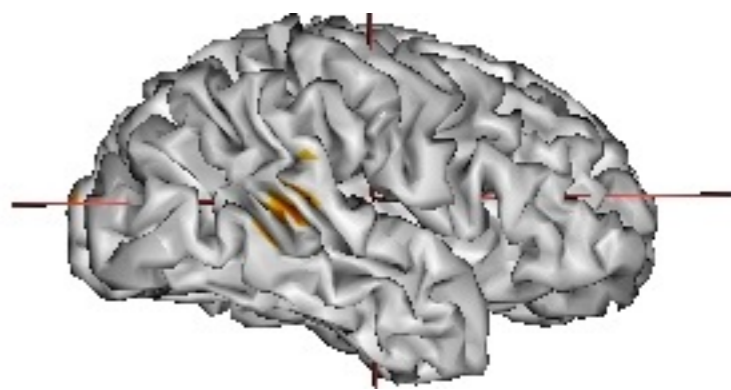
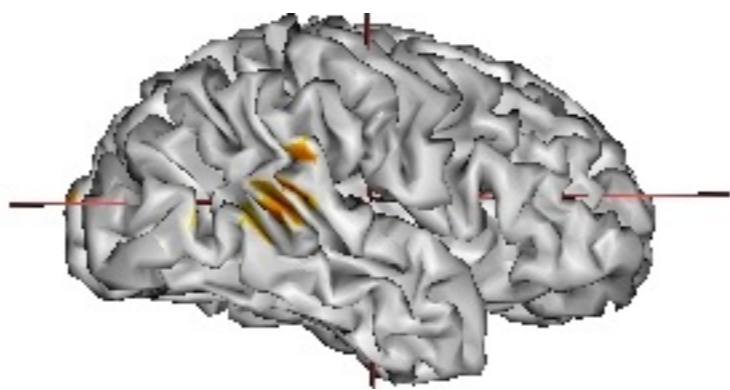
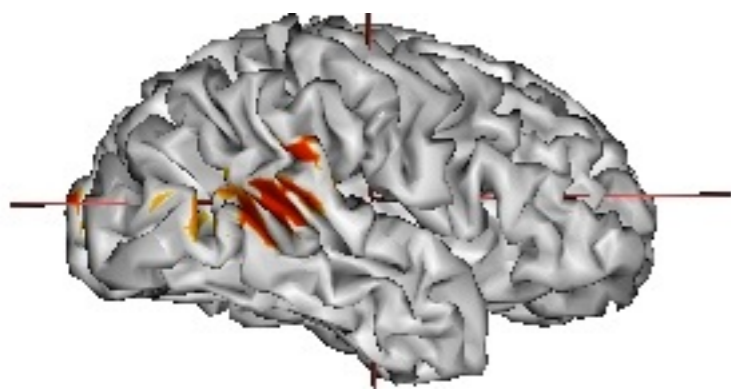
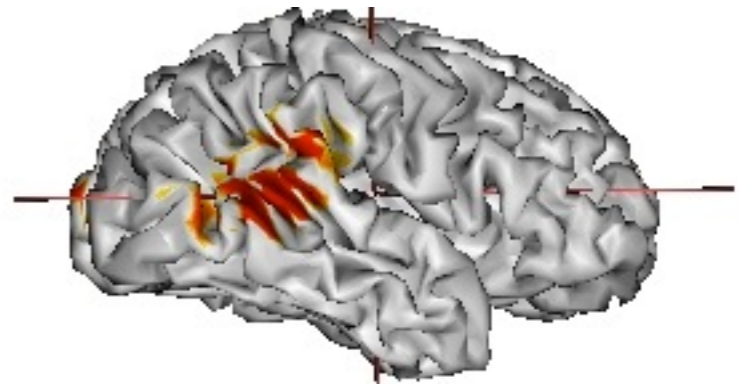
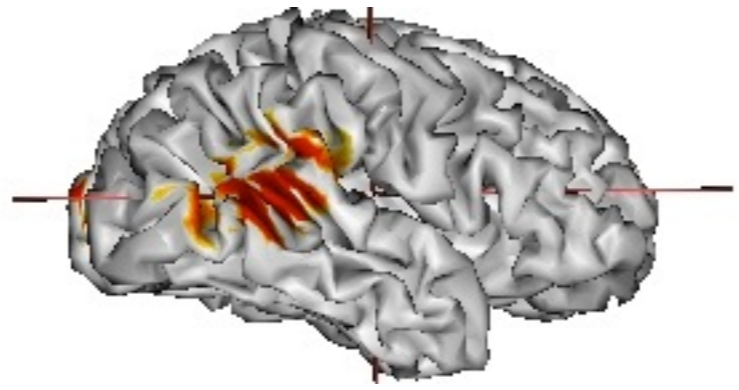
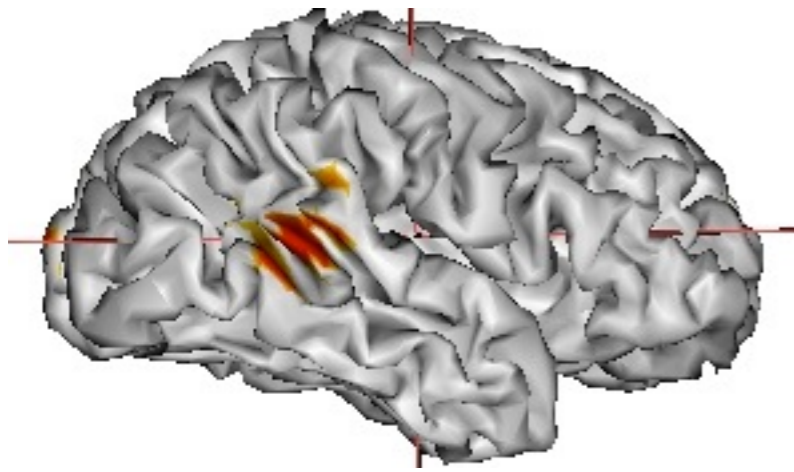
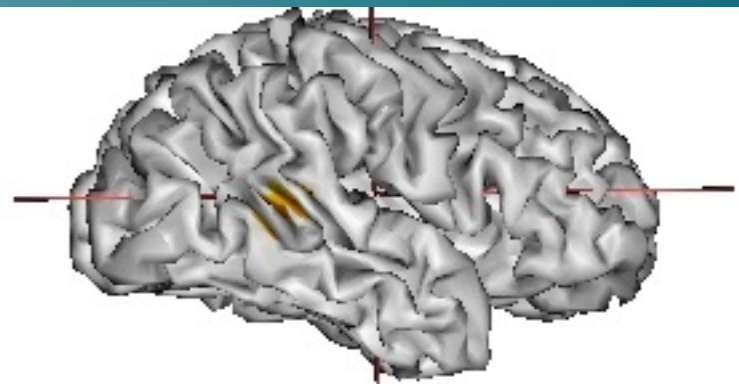
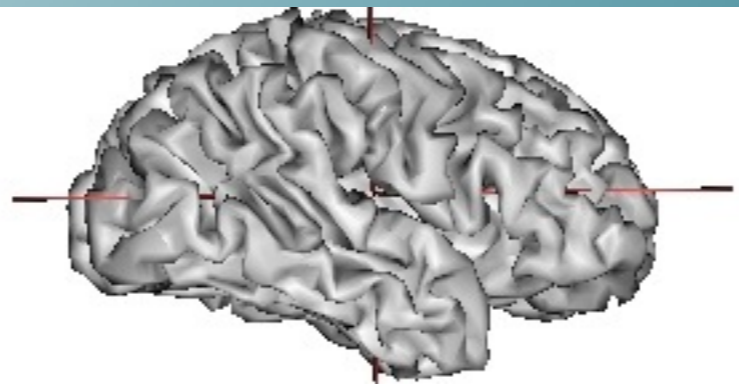
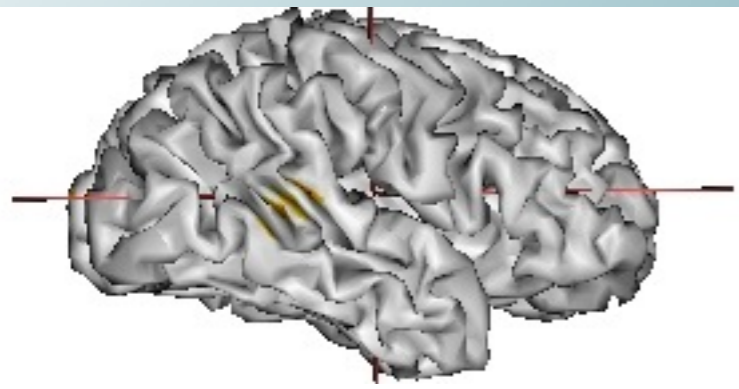
Signal Covariance

Depth Weighting

Noise Covariance

Noise level on each sensor
(diagonal element)

Correlation between sensors
(full matrix)

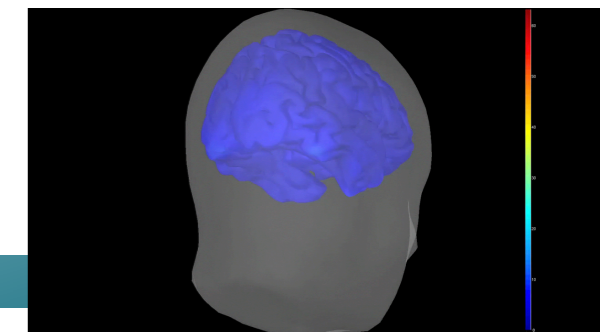
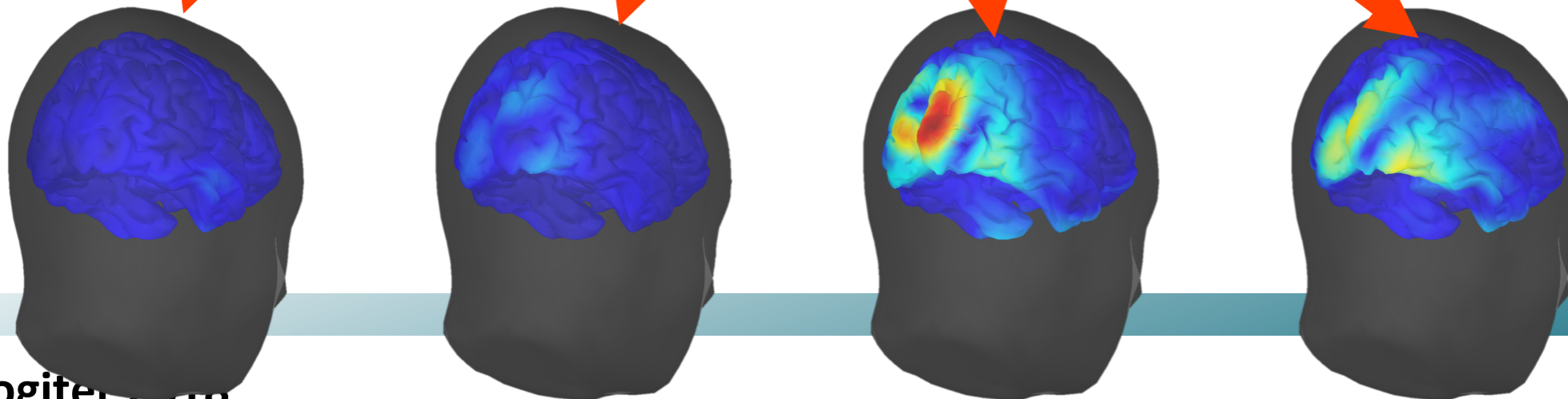
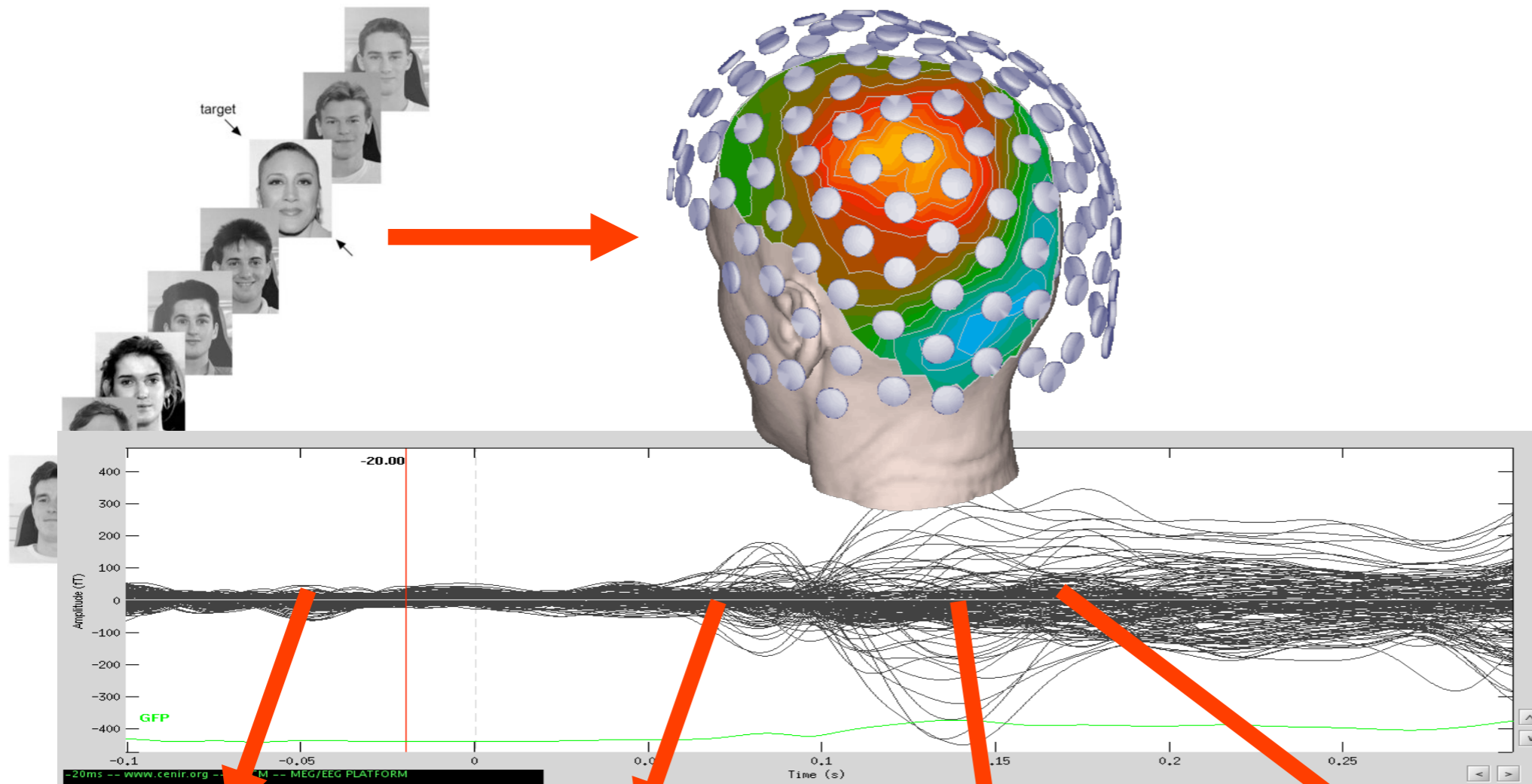


60 70 ms

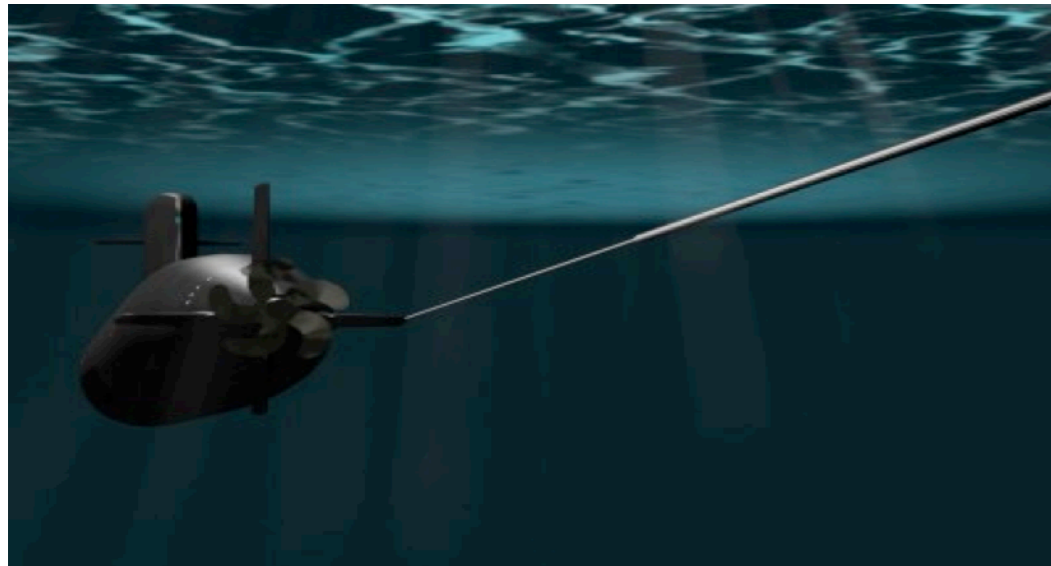
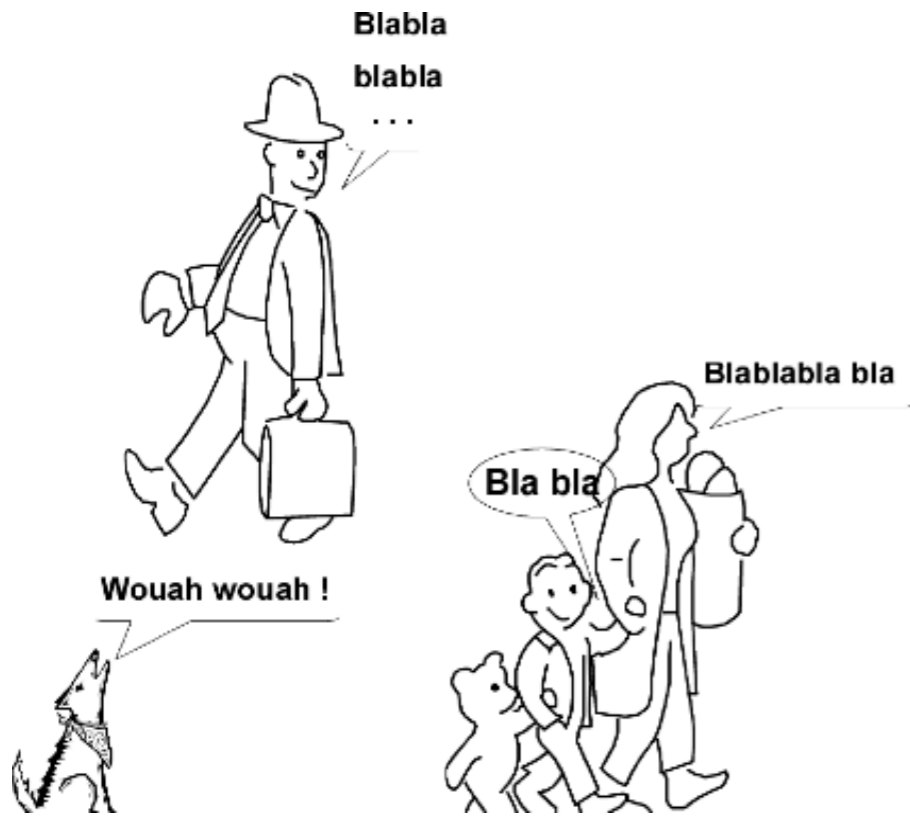
70 80 ms

80 90 ms

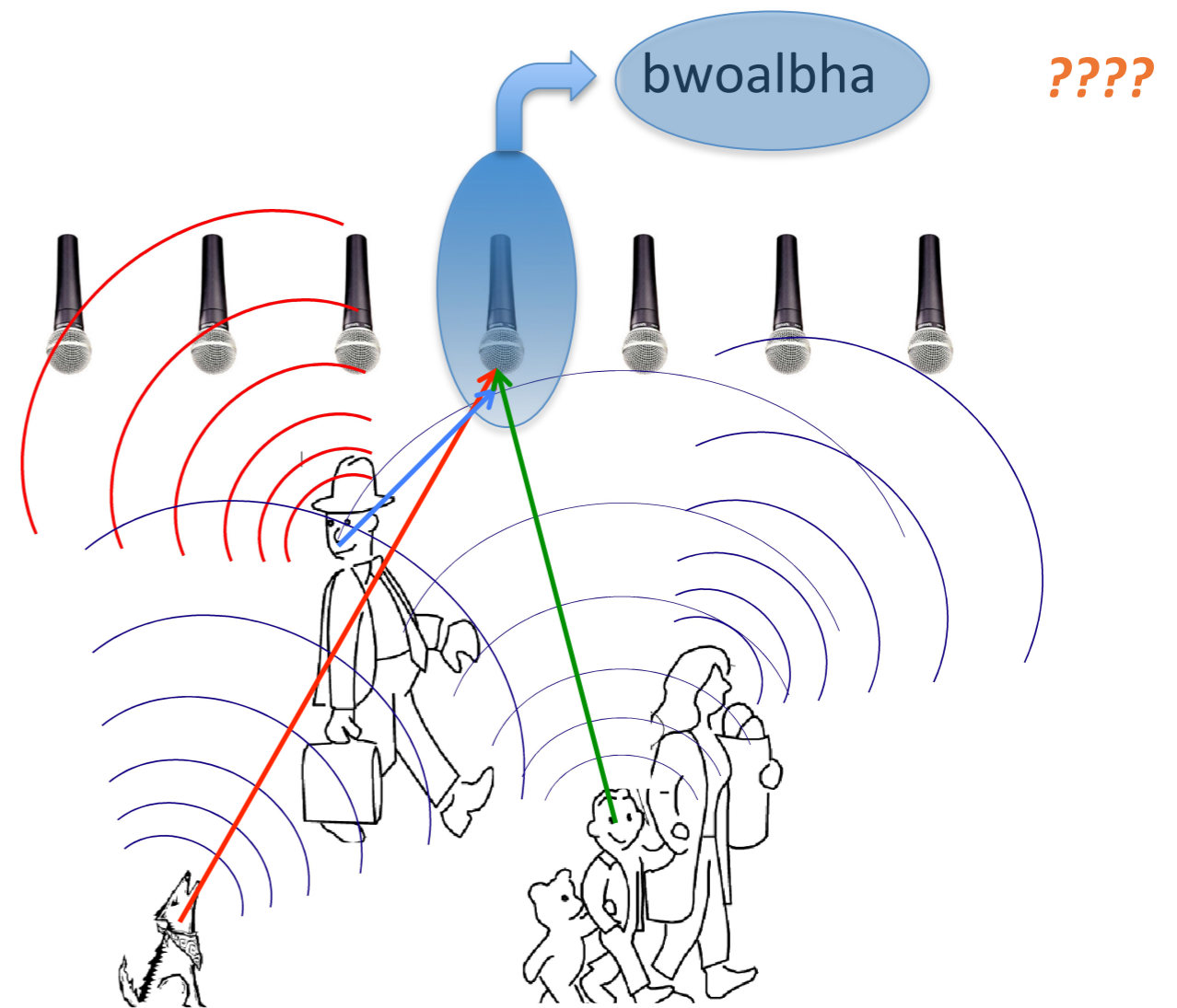
Le résultat sur le cortex



Beamforming « acoustique »

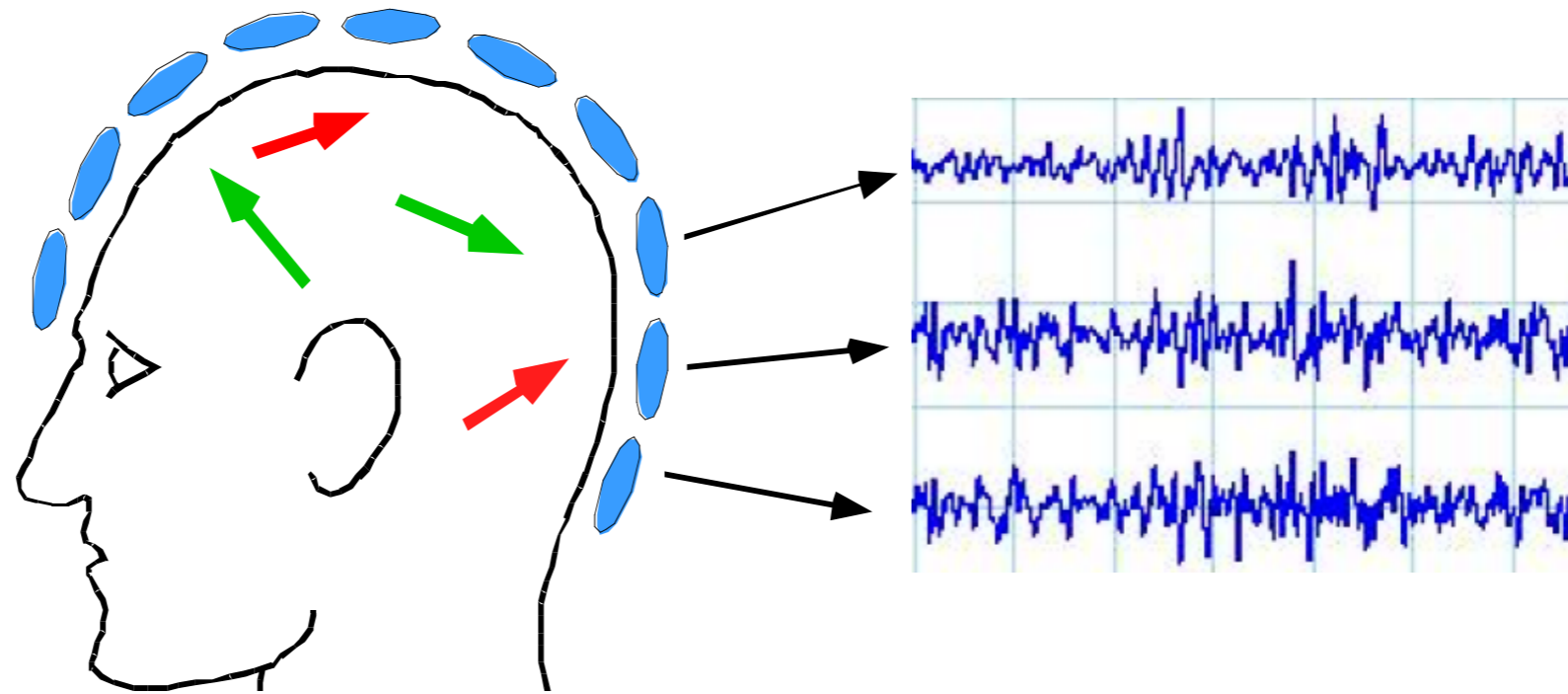


- détecter une source parmi du bruit et des interférences
- construire une carte du milieu : caractérisation de toutes les sources et détermination de leur position spatiale



Contexte et hypothèses

contexte :

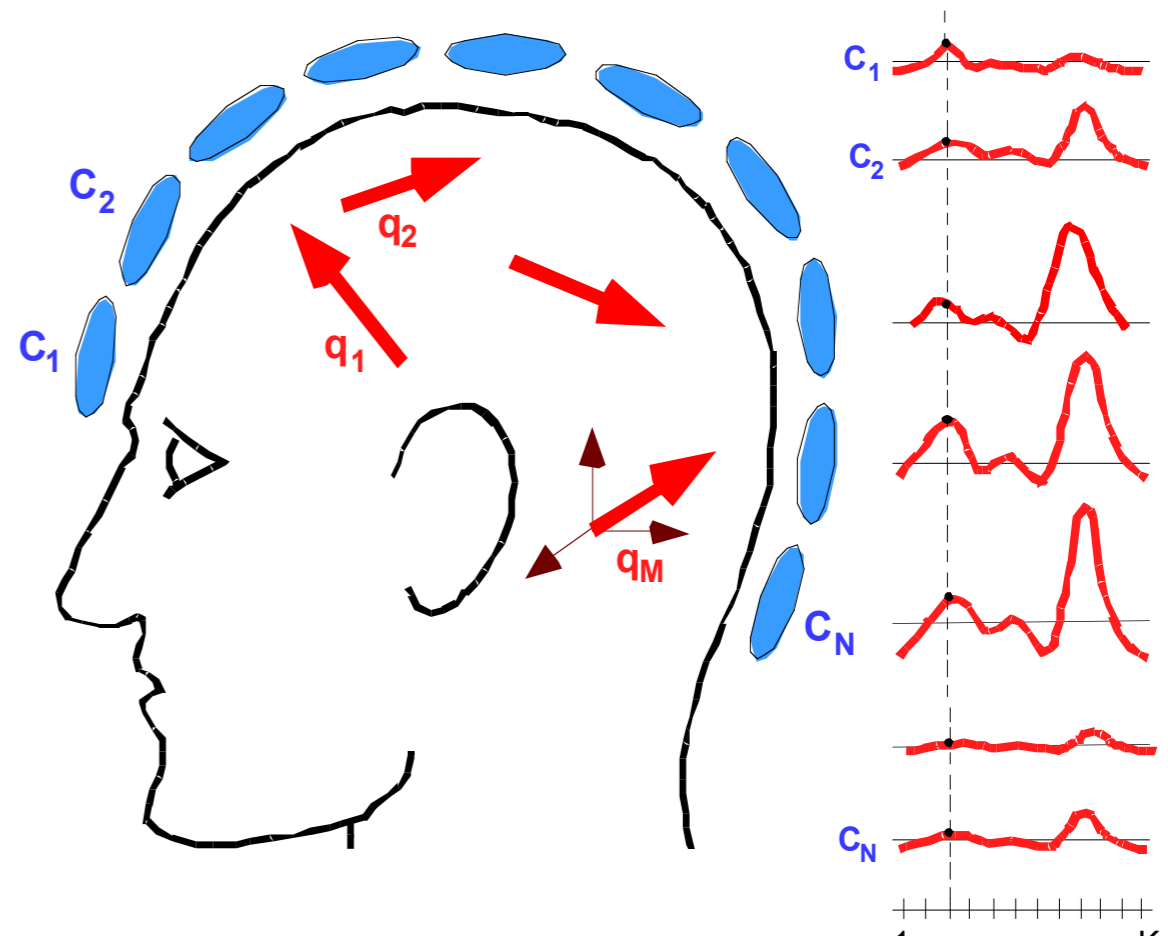


hypothèses

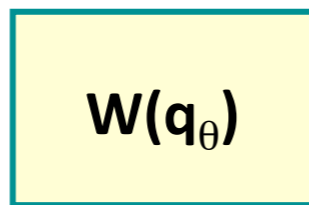
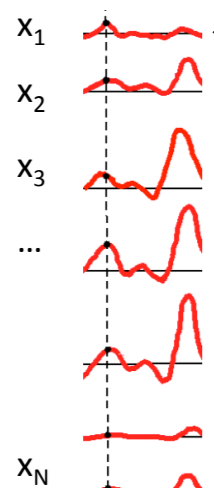
- onde plane : discrimination à partir de l'amplitude des signaux (pas de propagation)
- signaux stationnaires sur les périodes d'analyse (+-)
- nombre de sources < nombre de capteurs
- modèle dipolaire (ECD)
- sources non corrélées ou peu (< 0.8) sur la fenêtre d'analyse
- suffisamment de signal pour obtenir une solution stable

Notations

- N capteurs ($C_1, C_2, C_i \dots C_N$)
- M sources ($q_1, q_2, q_q \dots q_M$)
- K échantillons temporels



signal des capteurs



→ $y_{t\theta} = \sum w_\theta x_t$

sortie du filtre pour la source q_θ

Cartes SPM: « dual-state » differential imaging(4)

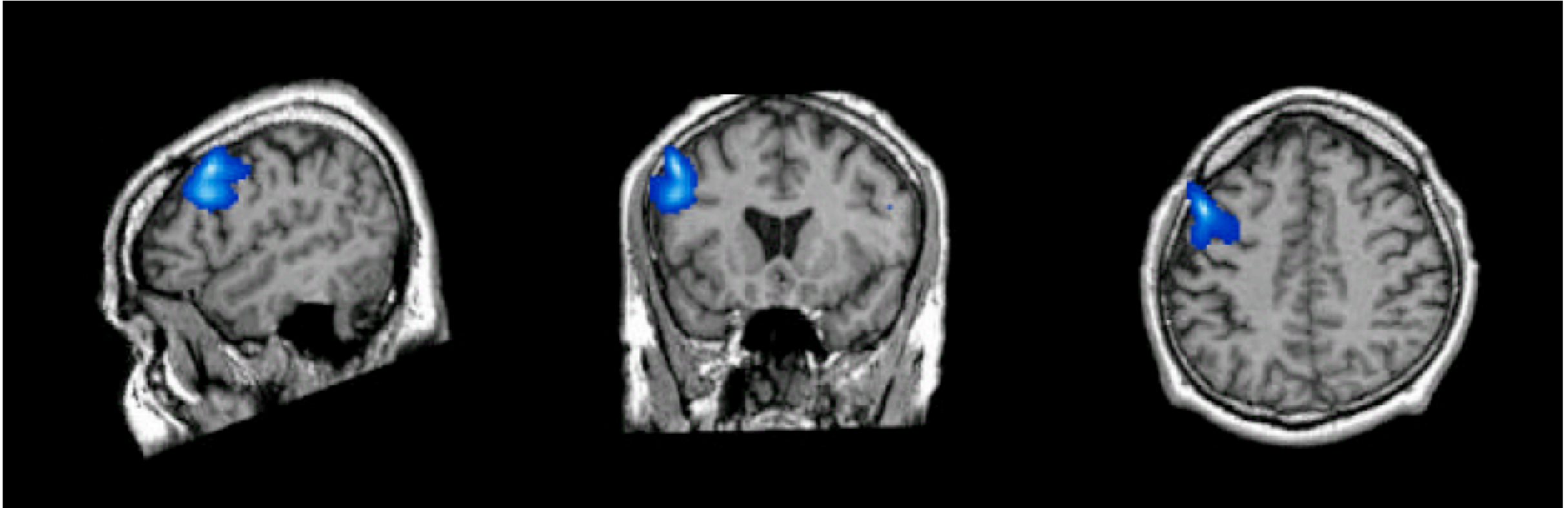


Figure 6. Dual-state SAM image in the 15 to 30 Hz frequency band of cortical activity during overt picture naming. A 143-channel MEG whole-head instrument was used to collect data in the open unshielded environment. Photographs of simple common objects were presented to the subject on an LCD screen. The subject's task was to identify the object and speak the name. The onset of vocalization was detected by a microphone, triggering each trial of data acquisition. The photograph remained on-screen for the duration of each of 100 trials. A pseudo-T image was generated from the difference in source activity between a time-segment prior to vocalization (the active state), and a time-segment after vocalization was completed (the control state). The blue coloration of the areas activated indicates event-related suppression in these regions. That is, rhythmic cortical activity was suppressed during the naming task, relative to the rest state following speech generation. Note that these changes are lateralized to the left hemisphere.

Et les sources profondes ?

Possible BUT

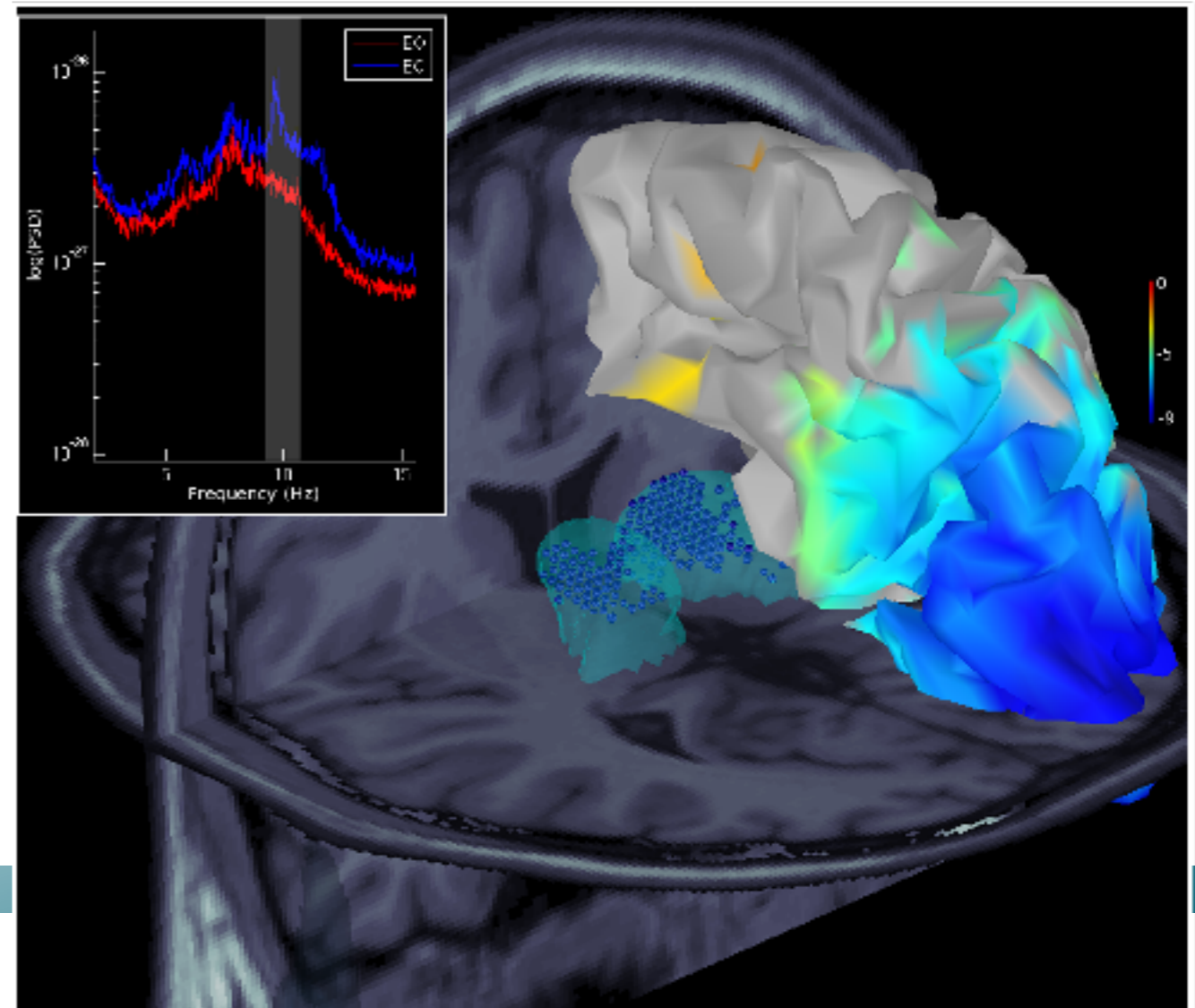
Very limited spatial resolution

Leakage from one structure to another

May necessitate heavy adaptation of protocols to increase SNR

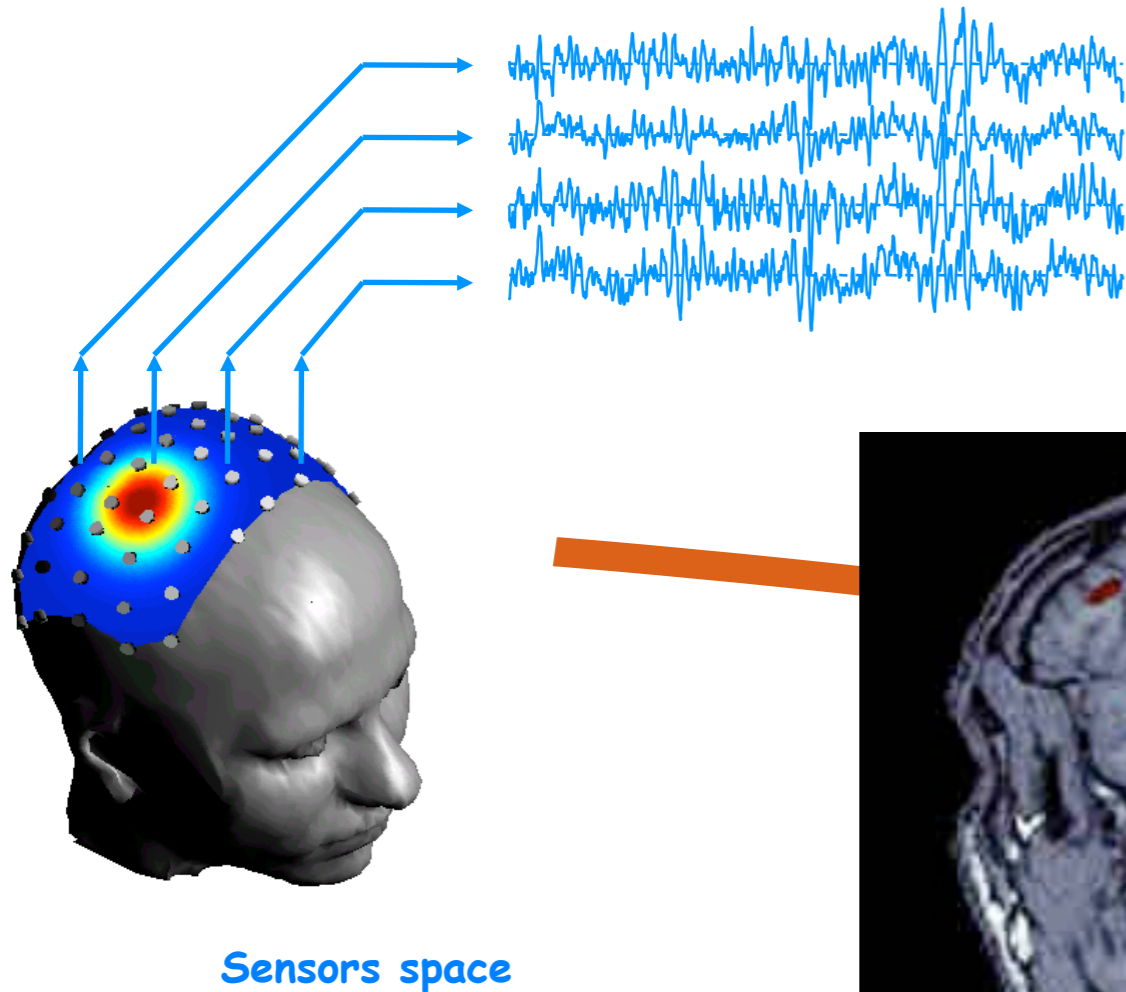
Work quite well for Amygdala,
Hippocampus, cerebellum

May work for thalamus

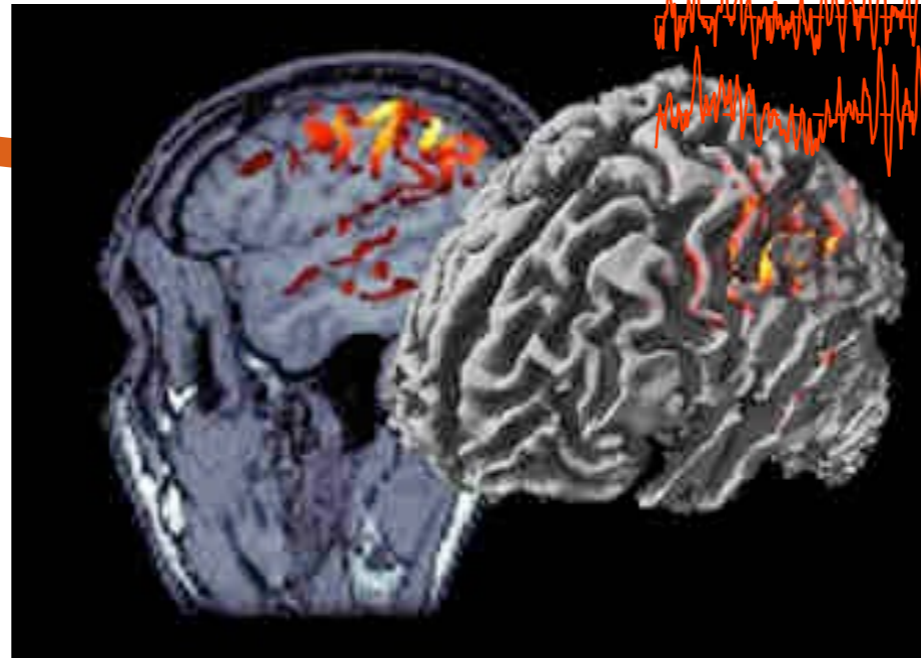
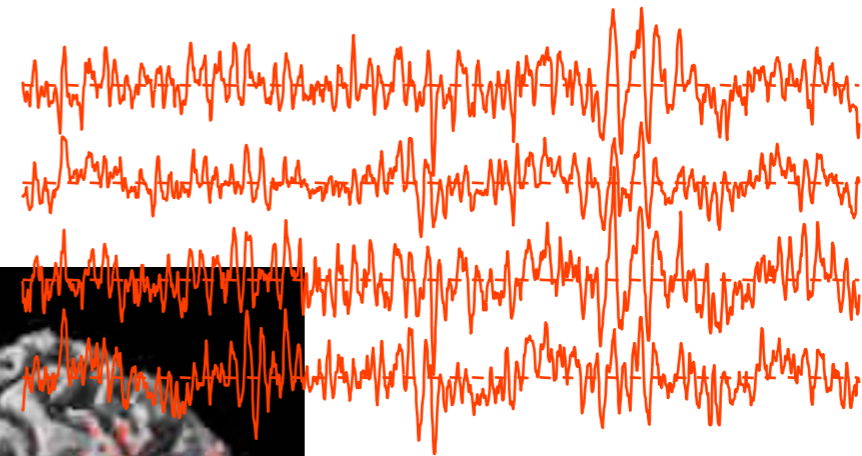


Connectivity?

MEG/EEG Acquisition

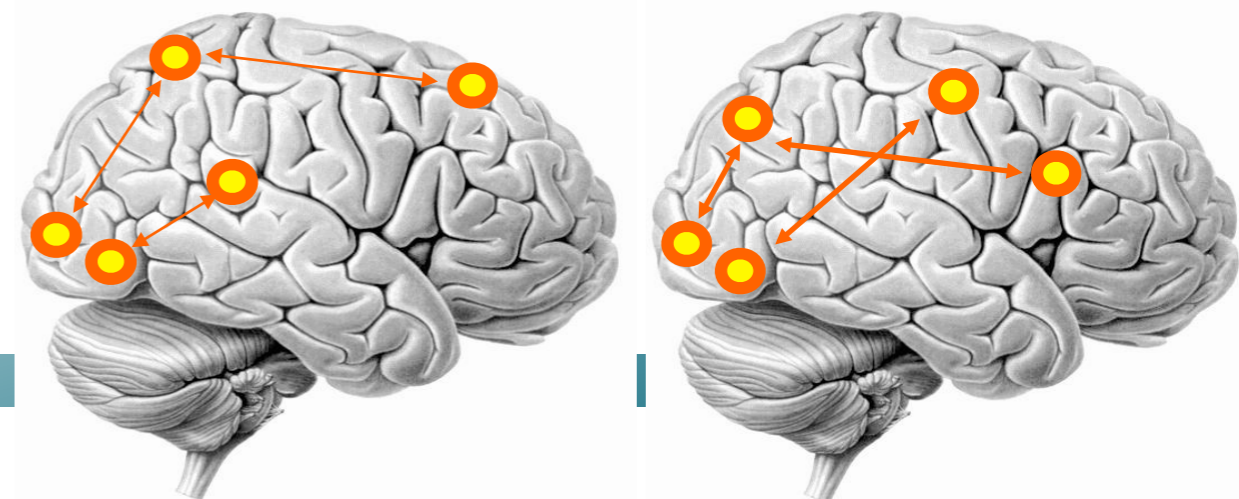


Cortical current



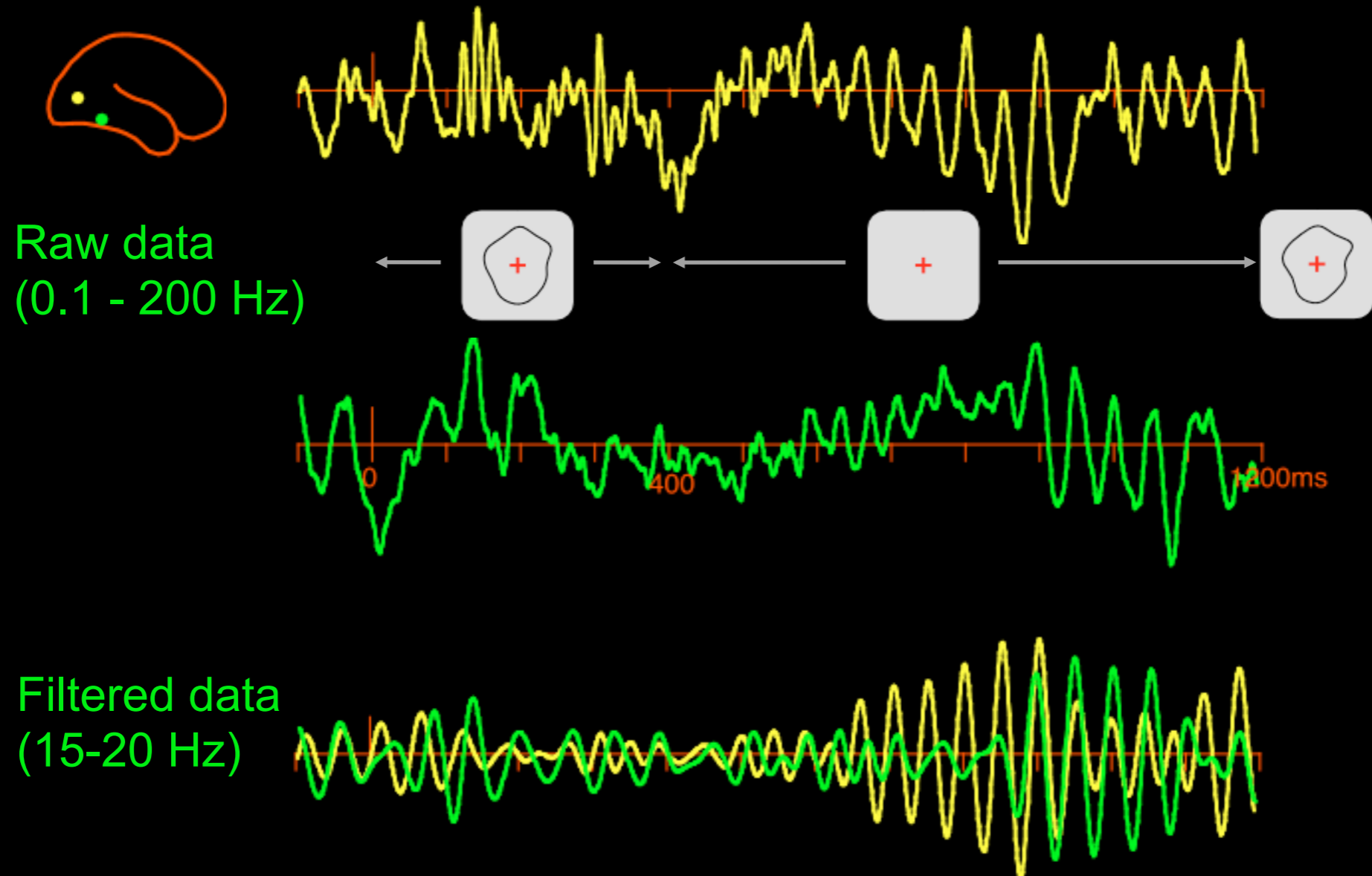
Sources space

Connectivity

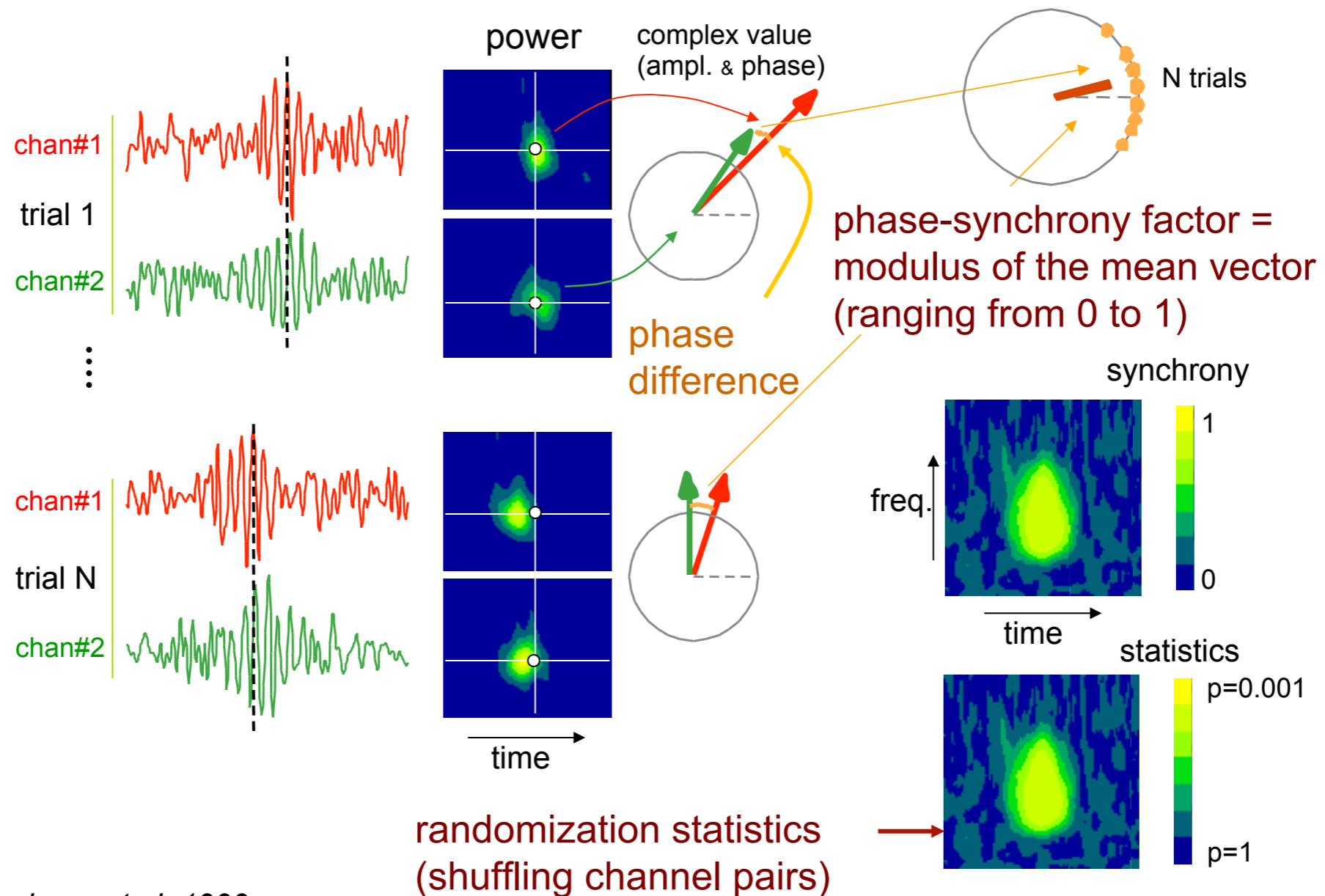


Synchronies?

Memory 2 - Raw data

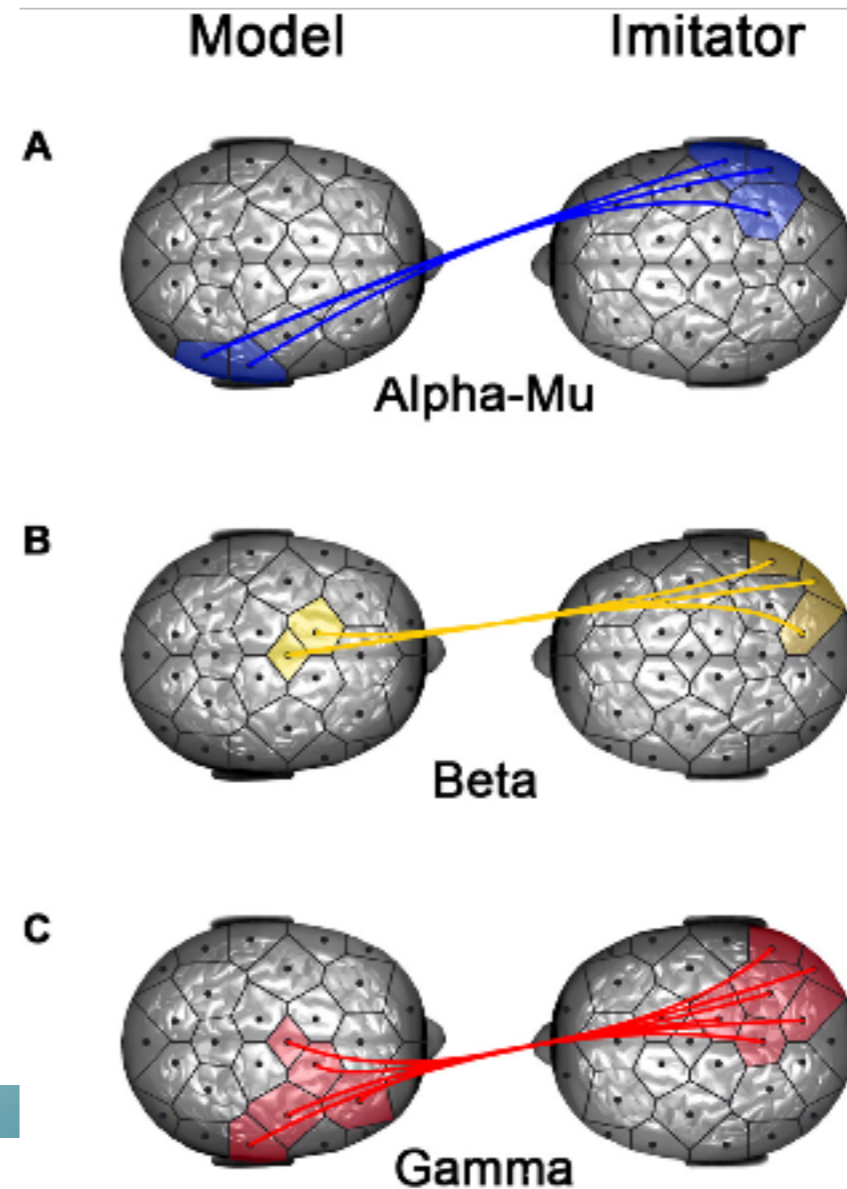
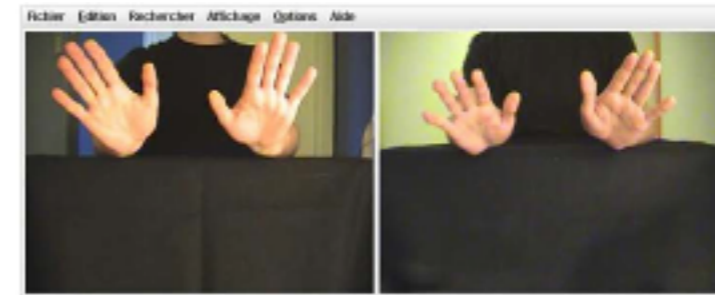
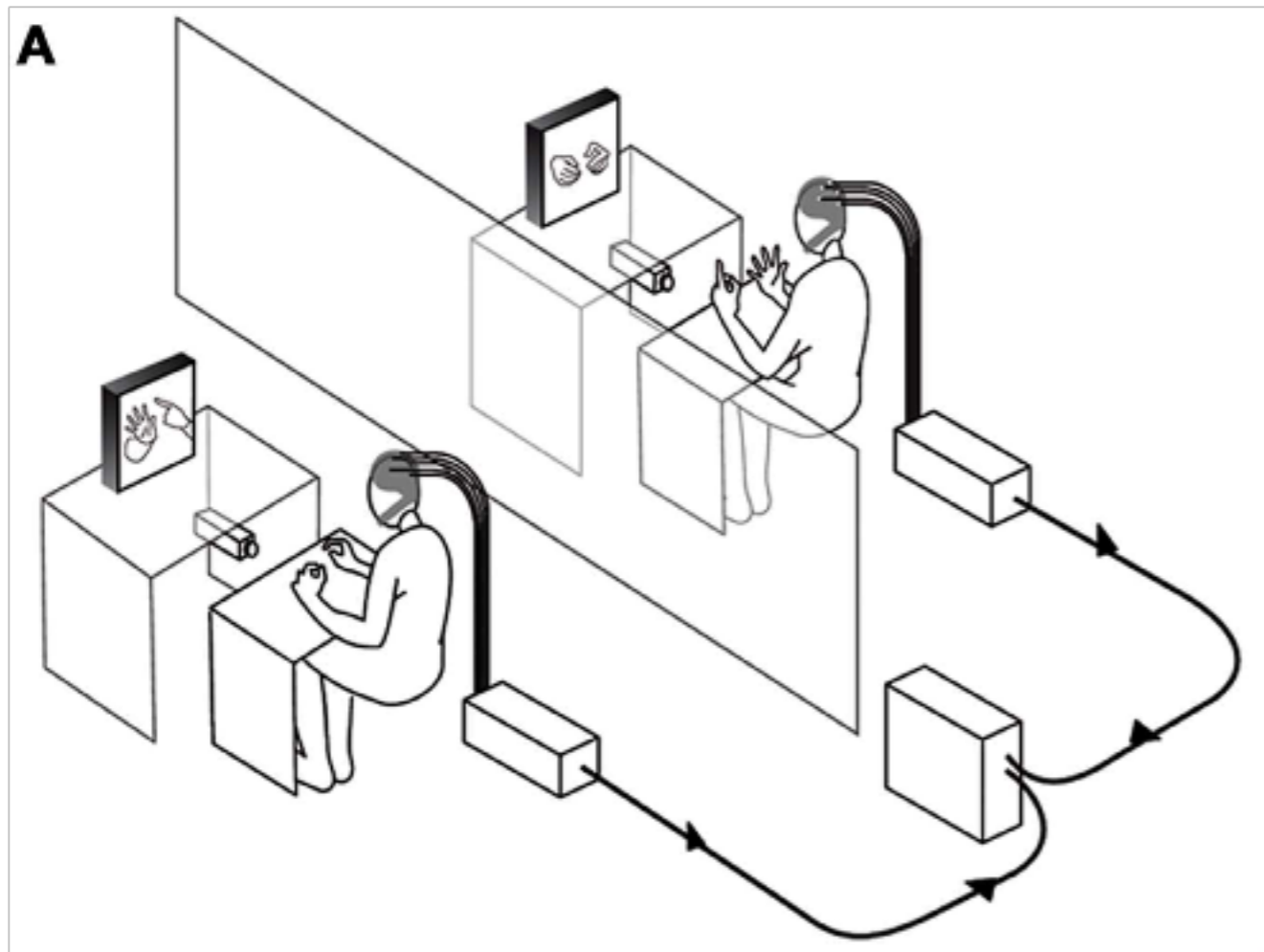


How do we measure synchronies?



Lachaux et al. 1999

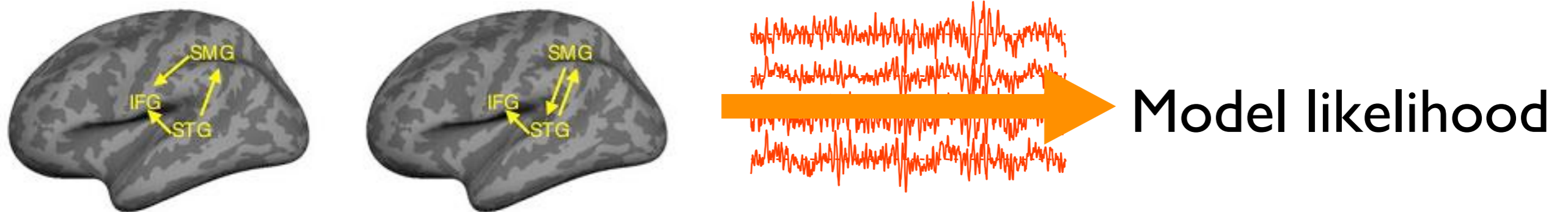
Between subjects????



A few words on causality

Describe the direction of the information flows

- Two possible ways
- Dynamic Causal Modeling [Model driven]

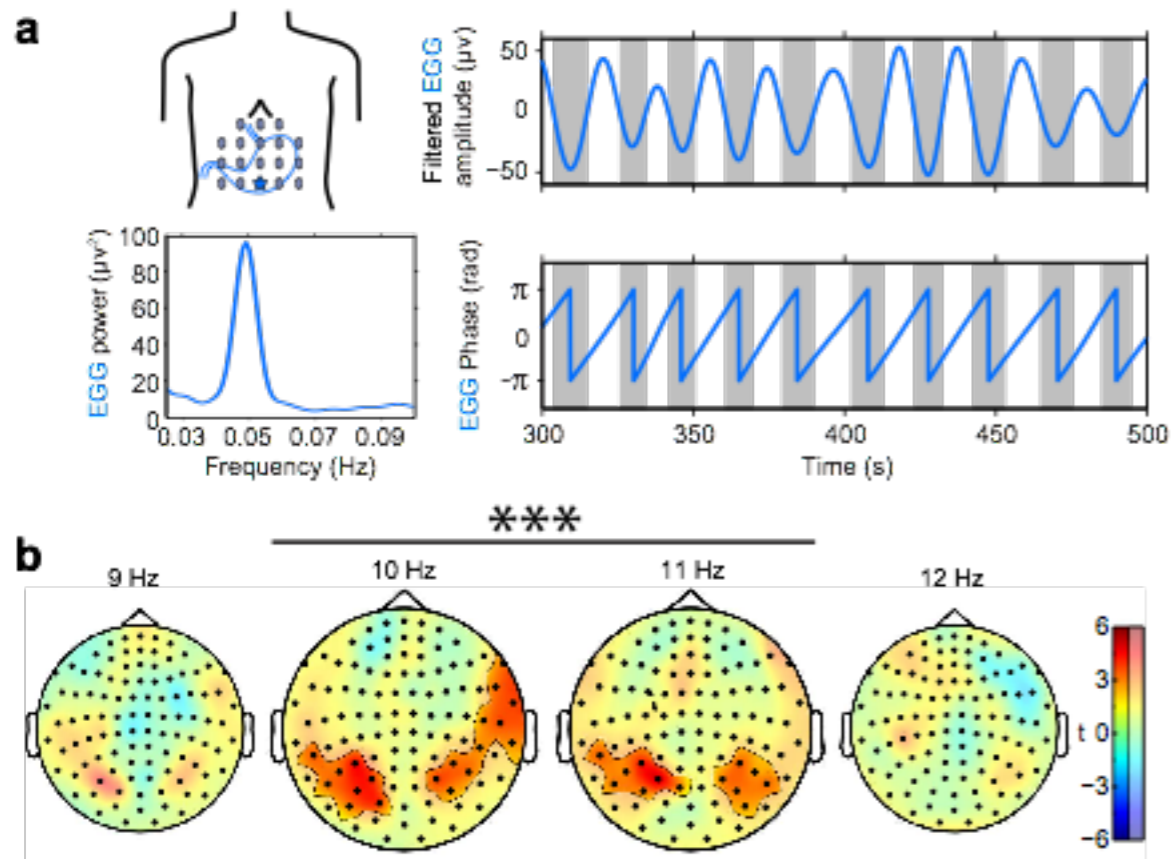


- Granger Causality [Data Driven]

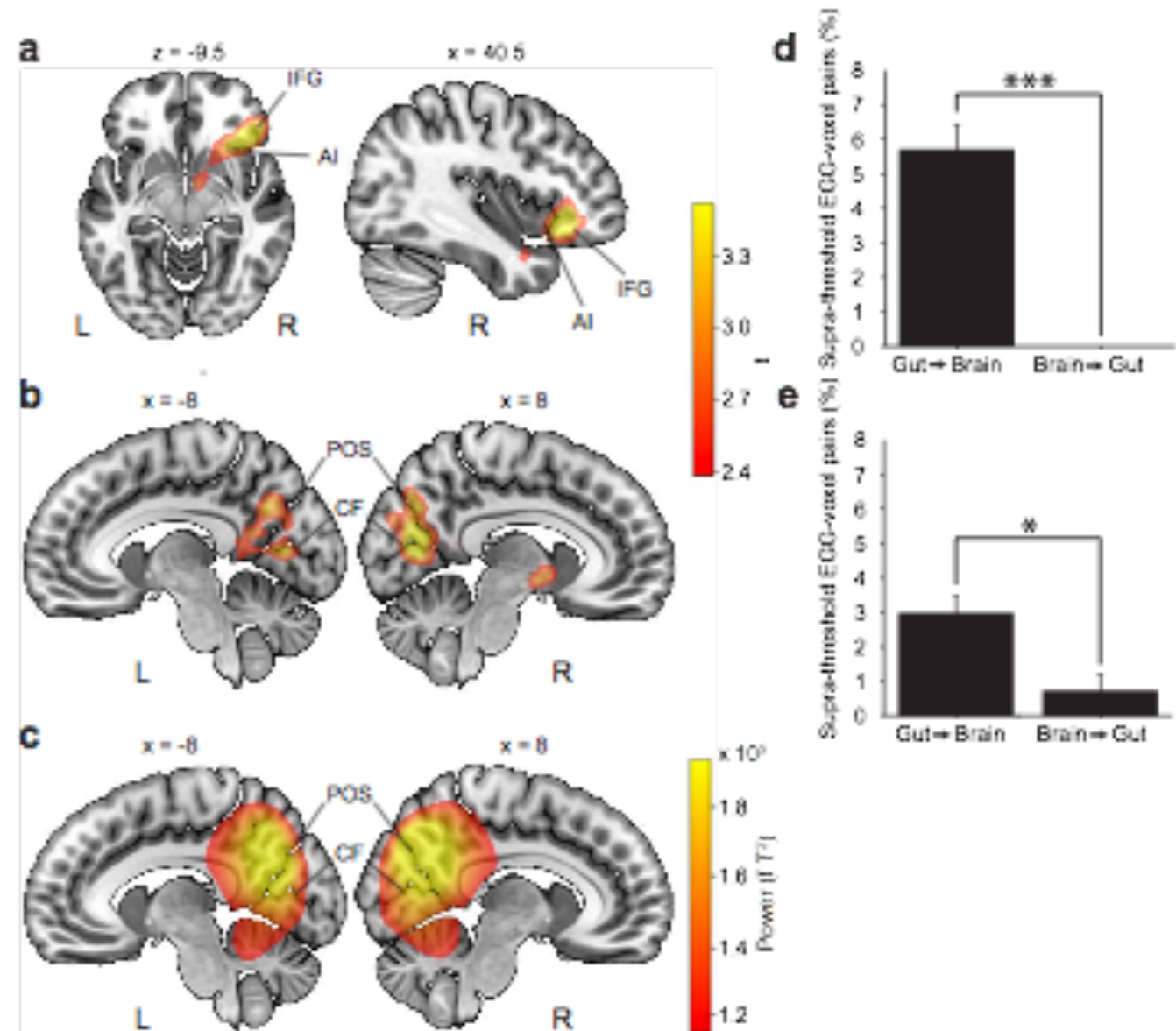


Stomach and brain interactions

The amplitude of spontaneous alpha rhythm fluctuations varies with the phase of the infra-slow gastric basal rhythm. Richter et collaborateurs, NeuroImage 2016.



MEG in alpha band coupled to gastric basal rhythm



Causality shows mainly Gut to Brain information flow.

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LETTER

doi:10.1038/nature26147

Moving magnetoencephalography towards real-world applications with a wearable system

Elena Boto^{1*}, Niall Holmes^{1*}, James Leggett^{1*}, Gillian Robertson¹, Sofie S. Meyer^{2,4}, Leonardo Duque Muñoz³, Karen J. Mullinger^{1,2}, Tim M. Tierney³, Sven Bestmann¹, Richard Bowtell^{1,5} & Matthew J. Brookes^{1,5}



Modulation of a Light Beam by Precessing Absorbing Atoms

H. G. DENNETT

University of Washington, Seattle, Washington

(Received January 7, 1957)

DETECTION OF VERY WEAK MAGNETIC FIELDS (10^{-9} GAUSS) BY 87Rb ZERO-FIELD LEVEL CROSSING RESONANCES
 J. DUPONT-ROC, S. HAROCHE and C. COHEN-TANNOUDJI
 Faculté des Sciences, Laboratoire de Spectroscopie Hertzienne de l'ENS, associé au C.N.R.S., Paris, France
 Received 8 January 1969

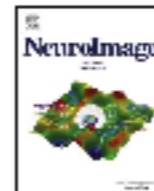
Zero-field level crossing resonances have been observed on the ground state of 87Rb . The width, a few microgauss, and the signal to noise ratio, about 2.5×10^3 , allow the measurement of 10^{-9} gauss fields.



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A new generation of magnetoencephalography: Room temperature measurements using optically-pumped magnetometers

Elena Boto^{a,1}, Sofie S. Meyer^{b,1}, Vishal Shah^c, Orang Alem^c, Svenja Knappe^c, Peter K. Mark Fromhold^d, Mark Lim^c, Paul M. Glover^b, Peter G. Morris^a, Richard Bowtell^{a,1}, & R. Barnes^{b,1}, Matthew J. Brookes^{a,1}



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Part IV. Hanle effect 259 – 300

THE HANLE EFFECT AND ITS USE FOR THE MEASUREMENTS OF VERY SMALL MAGNETIC FIELDS

ALFRED KASTLER

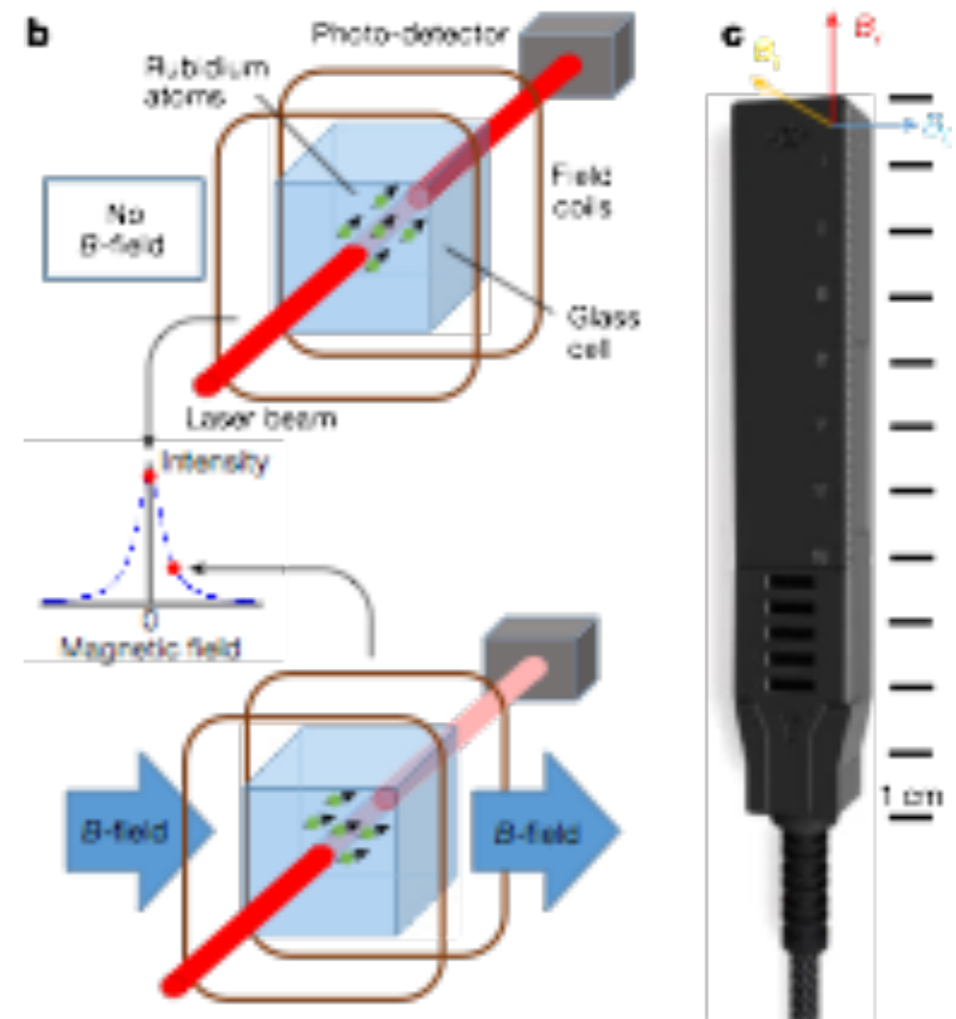
Laboratoire de Physique, École Normale Supérieure, Université de Paris, 24, Rue Lhomond, Paris (5e), 1e, France

The Hanle effect is briefly reviewed. It is shown that optical pumping can be used to create alignment of states. The combined use of Hanle effect and optical pumping then permits one to measure magnetic fields as small as 10^{-9} G.

OPM - Principles

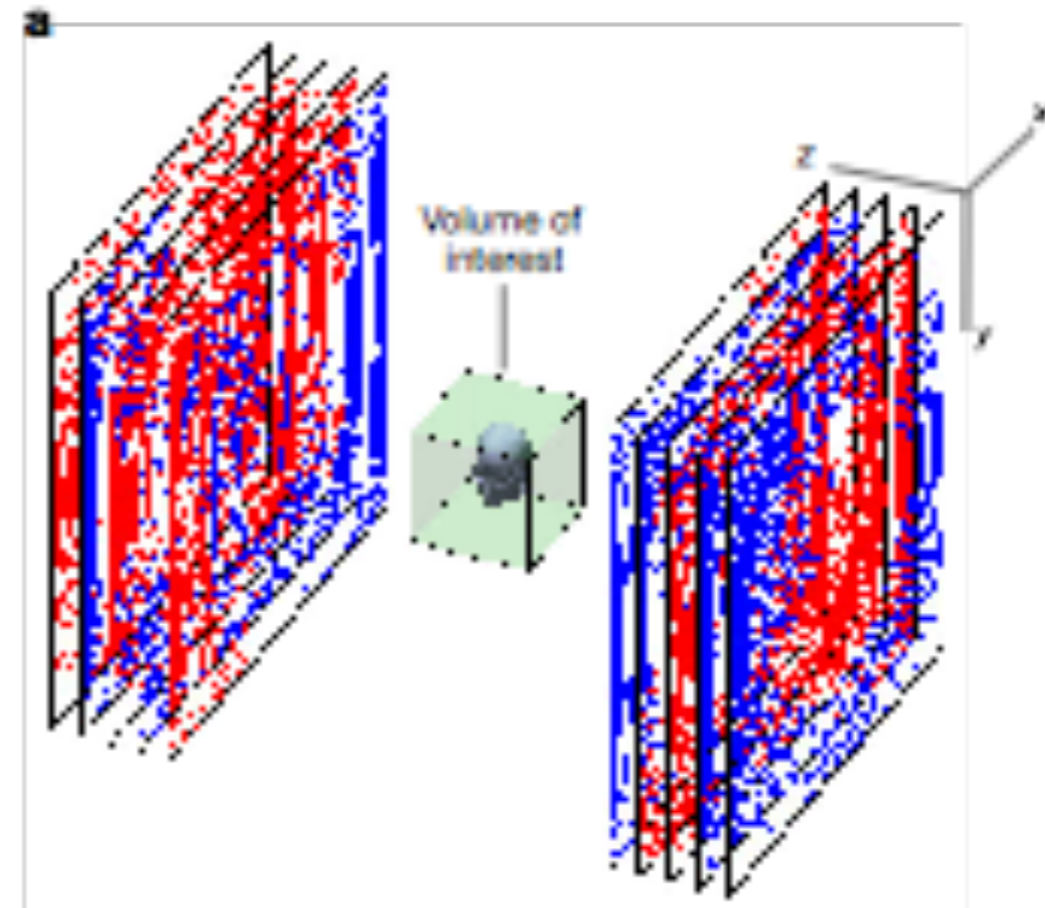
Vector / Scalar measure of small magnetic field through light transmission properties of gas

How? Thanks to precession and resonance phenomena

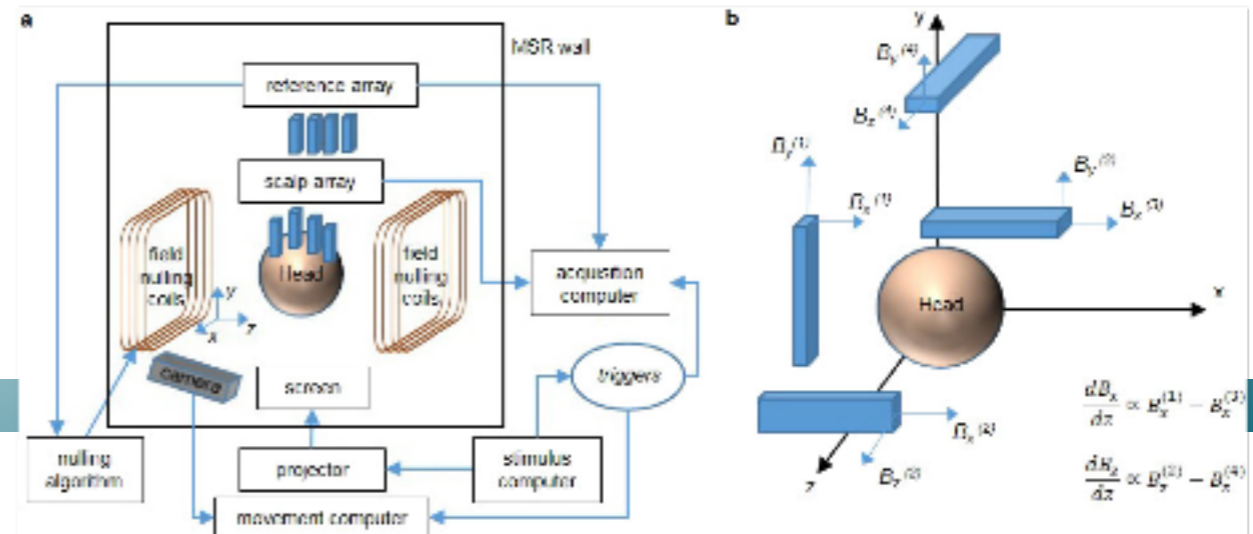


Sensitivity equivalent to SQUID < 130 Hz near ambient temperature

MEG system



LETTER RESEARCH

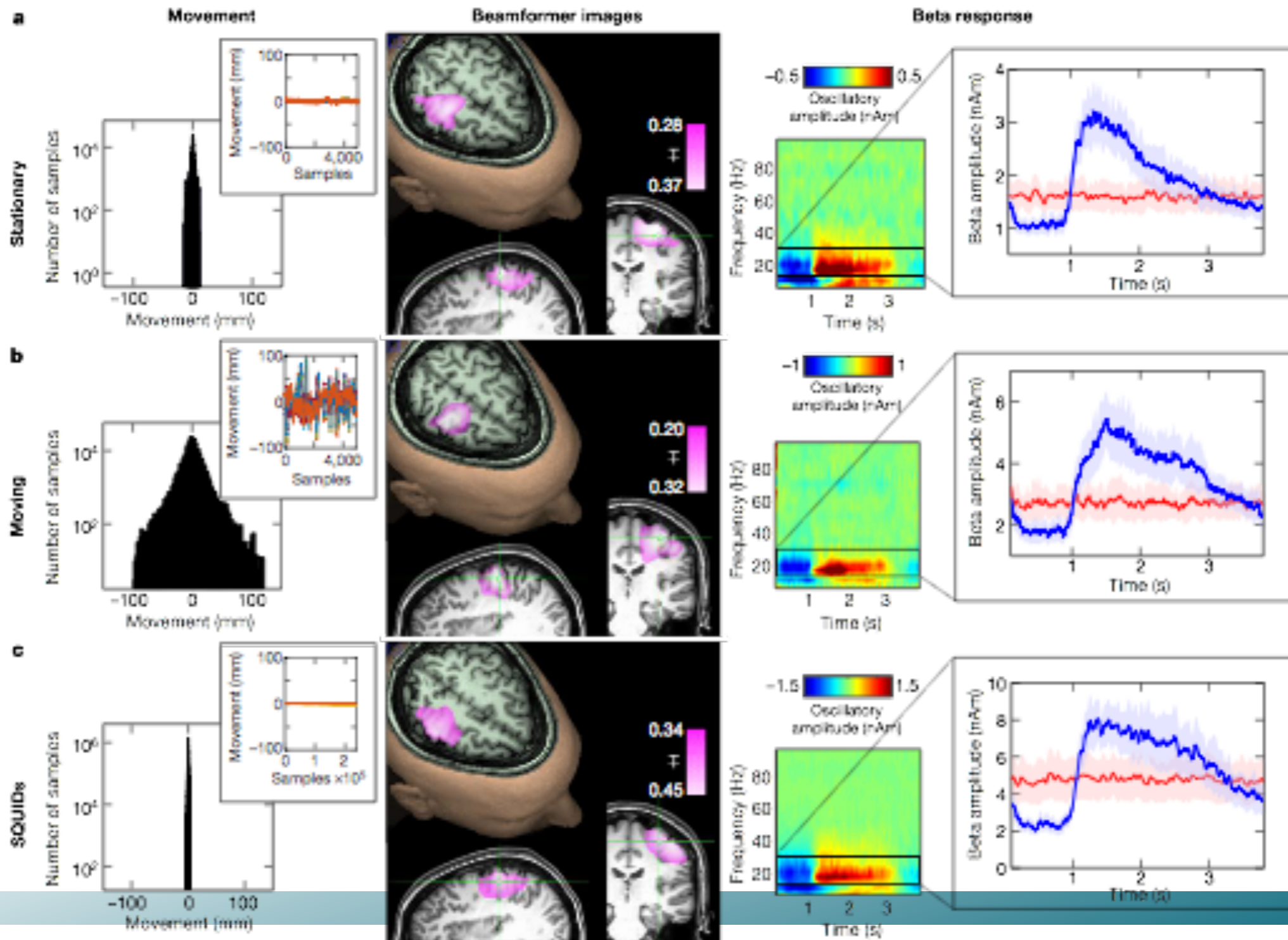


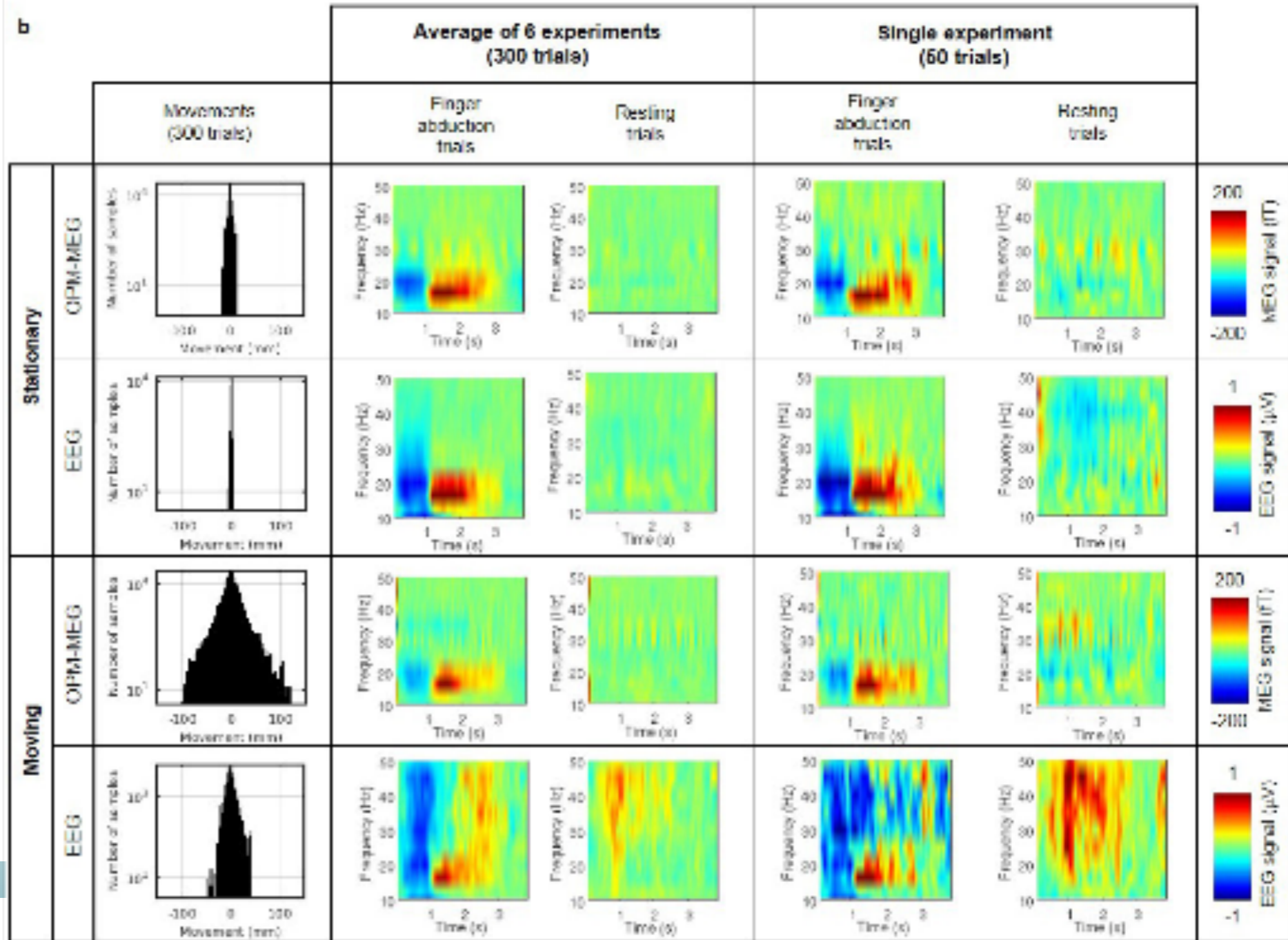
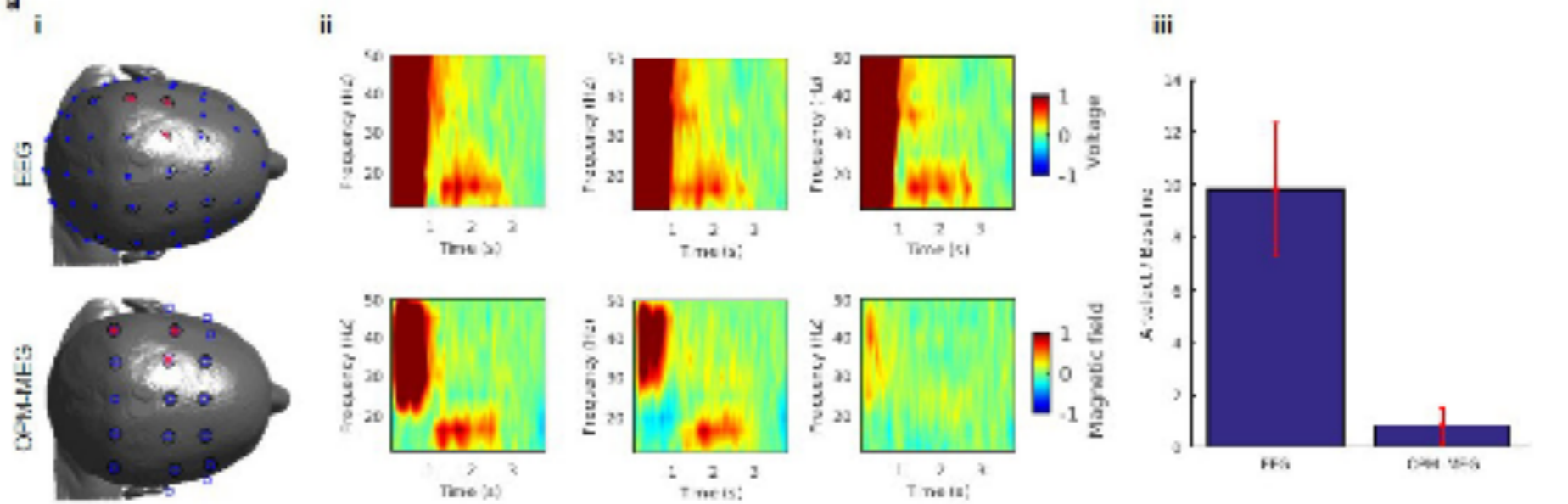
Helmet

an array of sensors that were mounted in a **3D-printed** ‘scanner-cast’. The scanner-cast¹² was designed using an **anatomical magnetic resonance imaging (MRI)** scan, such that the **internal surface snugly fits the subject’s** head, while the external surface accommodates the OPMs



it works :)





EEG



Portable / wireless EEG, Dry / Active Electrode

Multimodality

