# Connectivity–informed spatio–temporal MEG source reconstruction: Simulation results using a MAR model

Ivana Kojčić, Théodore Papadopoulo, Rachid Deriche, Samuel Deslauriers-Gauthier

## To cite this version:

Ivana Kojčić, Théodore Papadopoulo, Rachid Deriche, Samuel Deslauriers-Gauthier. Connectivity–informed spatio–temporal MEG source reconstruction: Simulation results using a MAR model. Colloque Line Garnero, Oct 2019, Paris, France. hal-02379744

HAL Id: hal-02379744
https://hal.inria.fr/hal-02379744
Submitted on 25 Nov 2019

# Connectivity–informed spatio–temporal MEG source reconstruction: Simulation results using a MAR model

Ivana **Kojčić**[1], Théodore **Papadopoulo**[1], Rachid **Deriche**[1] and Samuel **Deslauriers-Gauthier**[1]
Athena project–team, Inria, Université Côte d'Azur, Sophia Antipolis, France

Contact: ivana.kojcic@inria.fr
http://team.athena.inria.fr

**Abstract**: Recovering brain activity from M/EEG measurements is an ill–posed problem and prior constraints need to be introduced in order to obtain unique solution [1]. The majority of the methods use spatial and/or temporal constraints, without taking account of long–range connectivity. In this work, we propose a new connectivity–informed spatio–temporal approach to constrain the inverse problem using supplementary information coming from diffusion MRI. We present results based on simulated brain activity using a Multivariate Autoregressive Model, with realistic subject anatomy obtained from Human Connectome Project [4] dataset.

## 1. The forward problem

The relationship between source amplitudes and M/EEG measurements is expressed by the following linear model:

$$\boxed{M = GJ + \epsilon}$$

where

- $M \in \mathbb{R}^{N\times T}$ matrix of M/EEG signals measured at **N sensors** at **T time instants**
- $G \in \mathbb{R}^{N\times S}$ forward operator (leadfield matrix), where each column corresponds to forward field of one of **S sources**
- $J \in \mathbb{R}^{S\times T}$ unknown matrix of S source amplitudes (current distribution) along time
- $\epsilon$ additive white Gaussian noise

- The source space of size $S$ is parcellated into **R cortical regions** according to Desikan–Killiany atlas [5], where R=68 (S>>R).
- **Brain** is modelled as a simple undirected **graph** with **R nodes**.

## 2. The inverse problem

Consider the minimization problem: $\hat{J} = \arg\min_J \{\|M - GJ\|_2^2 + \lambda\|LJ\|_2^2\}$

**LORETA**

- Low resolution brain electromagnetic tomography (**LORETA**) [2] assumes simultaneous and synchronous activations of neighbouring brain areas.
- Maximally smooth solution – minimial norm of discrete Laplacian of the current distribution.

**Our approach**

- Include supplementary information from diffusion MRI in the regularization:
  - **anatomical** (long–range) **connections**
  - **transmission delays** $\mathbf{\Delta}_f$ between cortical regions

- Recovered source amplitudes are obtained by:

$$\hat{J}_L = (G^TG + \lambda L^TL)^{-1}G^TM$$

$$\hat{J}_C = (\widetilde{G}^T\widetilde{G} + \lambda\widetilde{L}^T\widetilde{L})^{-1}\widetilde{G}^TM$$

$\lambda^*$– optimal **regularization parameter** – chosen using Generalized Cross-Validation

- **L** – symmetric normalized **Laplacian matrix** computed on the cortical regions:

$$L^{symm} = I - D^{-1/2}AD^{-1/2}$$

- **D** – degree matrix
- **A** – symmetric (R × R) **adjacency** (connectivity) **matrix** on the cortical mesh with elements:

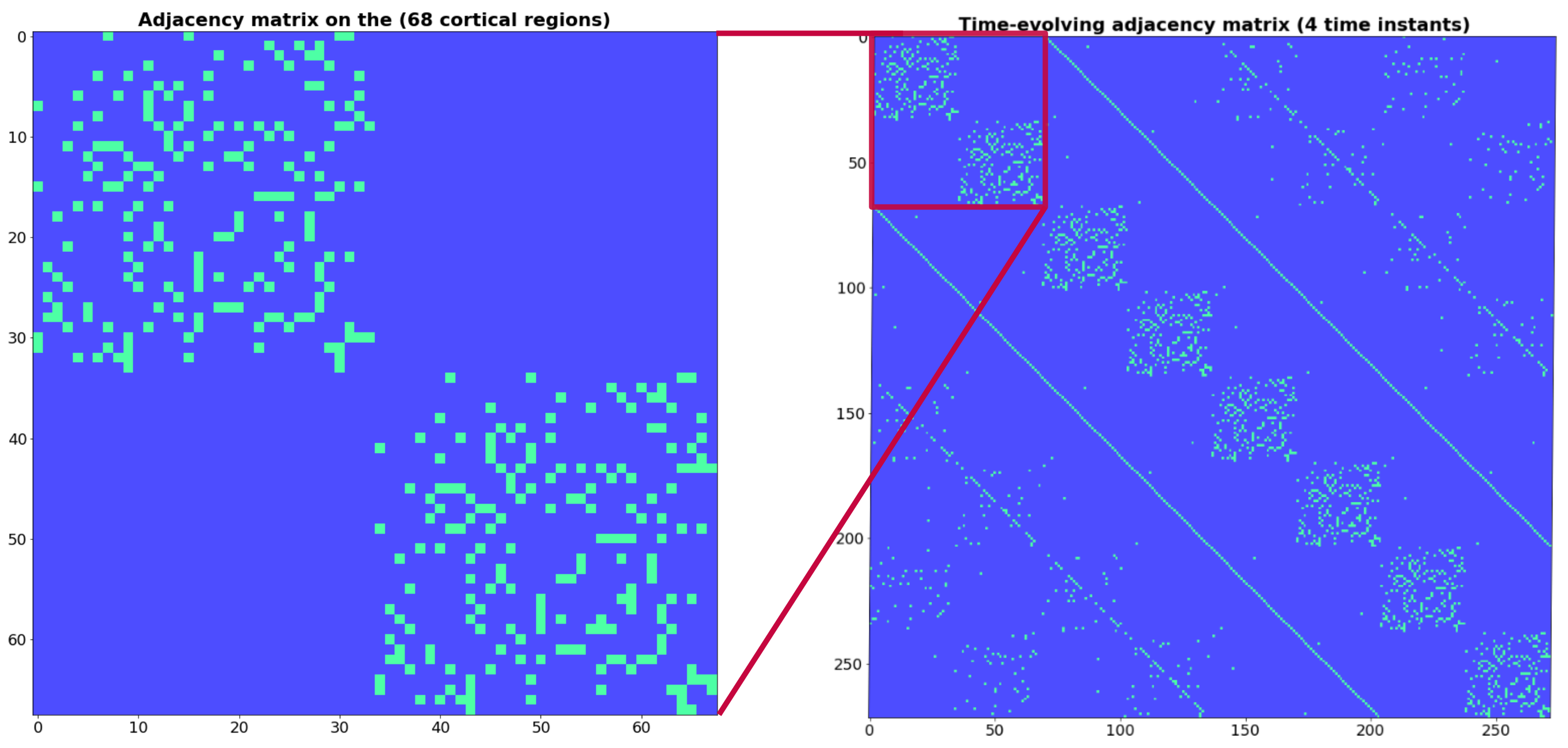
$$a_{ij} = \begin{cases} 1, & \text{if vertices } i \ \& \ j \text{ are connected by an edge} \\ 0, & \text{otherwise} \end{cases}$$

- Edges between neighbouring nodes (adjacent brain areas) ➡ **short-range** connections

- $\widetilde{G}$ – block–diagonal leadfield matrix of size (N × T) × (R × T)
- $\widetilde{L}$ – **time–evolving** block–diagonal normalized **Laplacian matrix**
- $\widetilde{A}$ – spatio–temporal adjacency matrix of size (R × T) × (R × T) that evolves with time according to long-range connectivity
  - edges between neighboring nodes
  - **short-range & long-range** connections

$$\widetilde{A} = \begin{bmatrix} A_0 & A_1 & \dots & A_{T-2} & A_{T-1} \\ A_1 & A_0 & \dots & \dots & A_{T-2} \\ \vdots & \dots & \dots & \dots & \vdots \\ A_{T-2} & \dots & \dots & A_0 & A_1 \\ A_{T-1} & A_{T-2} & \dots & A_1 & A_0 \end{bmatrix}$$

Main block-diagonal matrices of $\widetilde{A}$
⬇
adjacency matrix on the cortical mesh
($\mathbf{A=A_0=A_{ii}}$)



## 3. Simulation of cortical activity

- Simulations were preformed using MNE-Python software [3] based on realistic subject anatomy from HCP dataset [4].
- Activity of all **sources** can be modeled as a Vector Autoregressive model [6] of order $p$ (**VAR($p$)**):

$$\boldsymbol{j}_t = \sum_{i=1}^{p} \boldsymbol{C}_i \boldsymbol{j}_{t-i} + \boldsymbol{\omega}_t \in \mathbb{R}^S$$

$$p = \max(\Delta_f) \qquad \Delta_f = \frac{f_{length}}{speed}F_s$$

⬇ max delay found in all $\boldsymbol{f}$ streamlines

**MAR coefficient matrices**

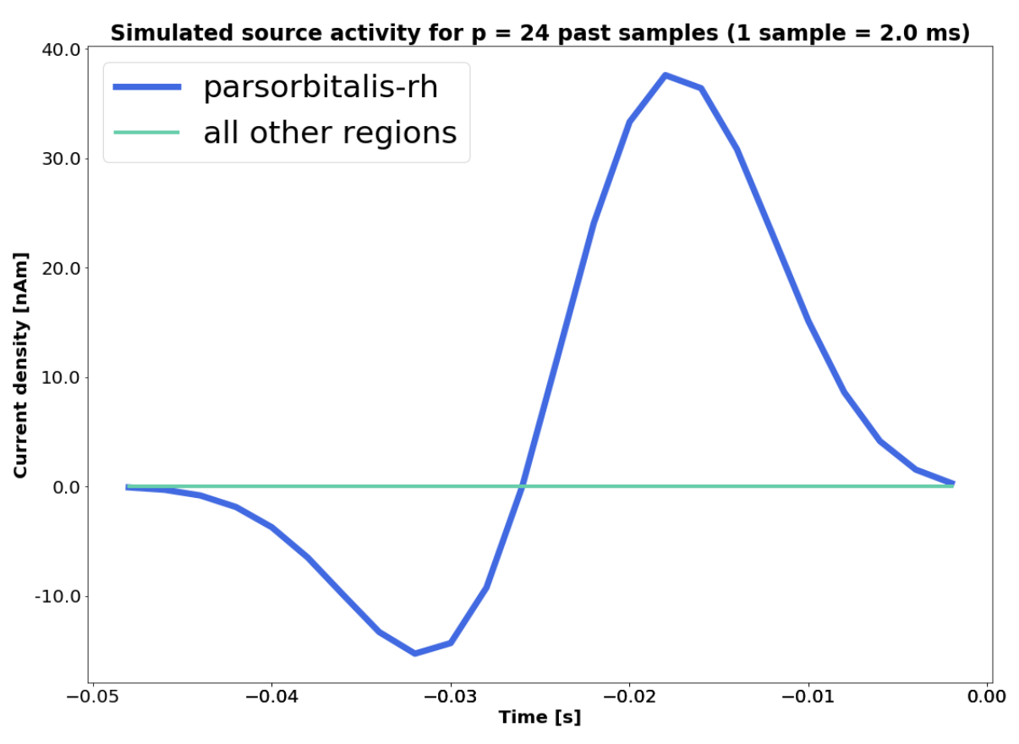
- $\boldsymbol{C}_i \in \mathbb{R}^{S\times S}$ matrix defines the contribution of all sources at time $\boldsymbol{t–i}$ to all sources at time $\boldsymbol{t}$

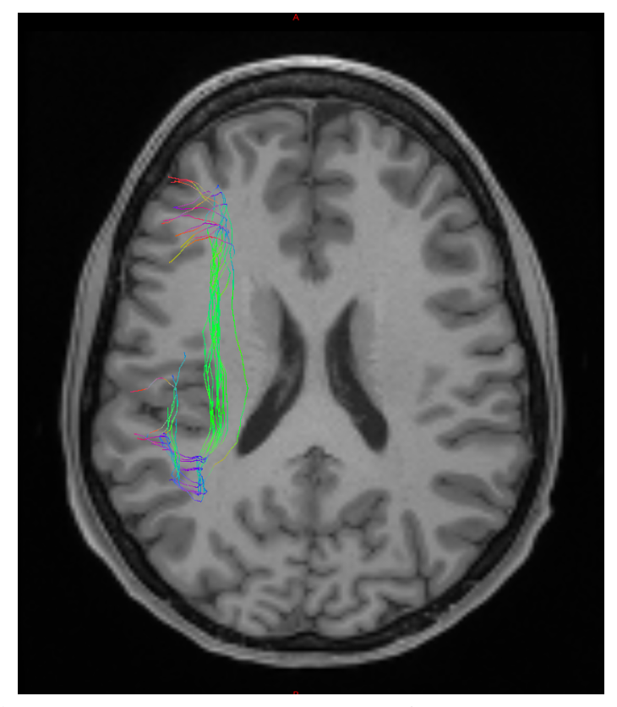
- **Dynamic source model** is defined by multivariate autoregressive **(MAR) model**:

$$\tilde{\boldsymbol{J}}_t = \tilde{\boldsymbol{C}}\tilde{\boldsymbol{J}}_{t-1} + \tilde{\boldsymbol{\omega}}_t = (\boldsymbol{j}_t, \boldsymbol{j}_{t-1}, ..., \boldsymbol{j}_{t-p+1})^T \in \mathbb{R}^{Sp\times 1}$$

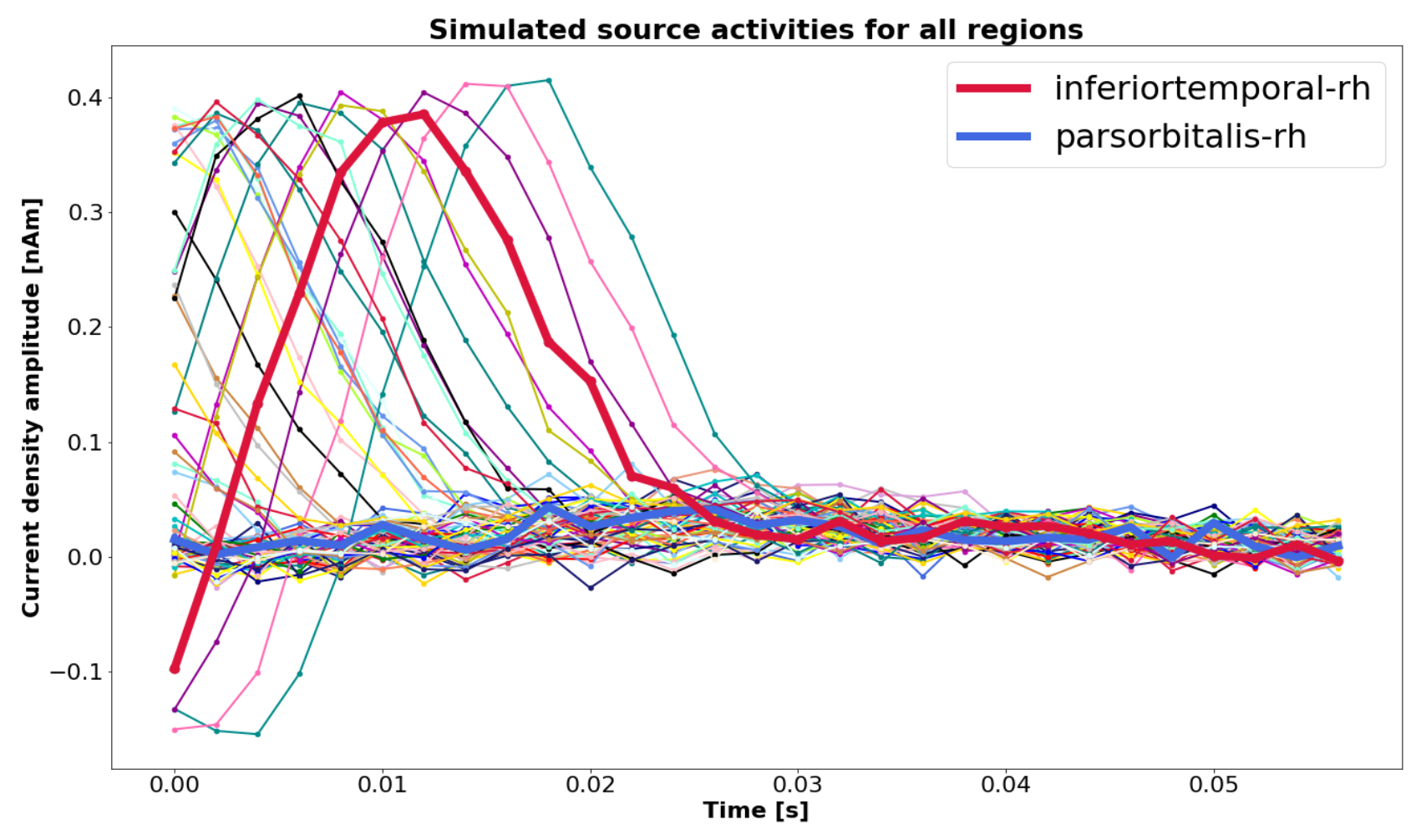
- $\tilde{\boldsymbol{C}} \in \mathbb{R}^{Sp\times Sp}$ augmented coefficient matrix

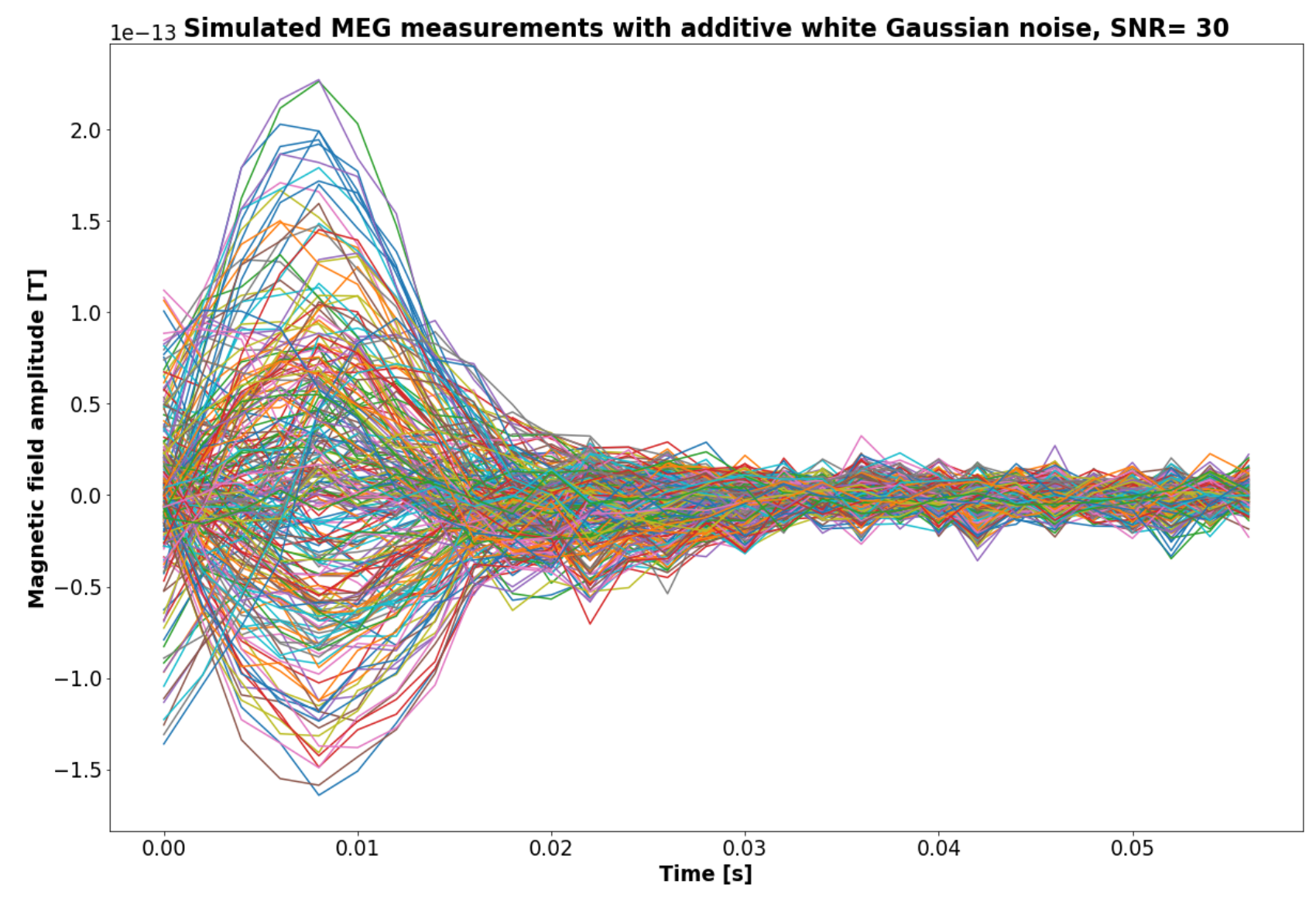
- Example: input signal (for $\boldsymbol{p}$ past samples) in right inferior frontal gyrus (**pars orbitalis**).





*Streamlines connecting inferior temporal lobe to pars orbitalis*



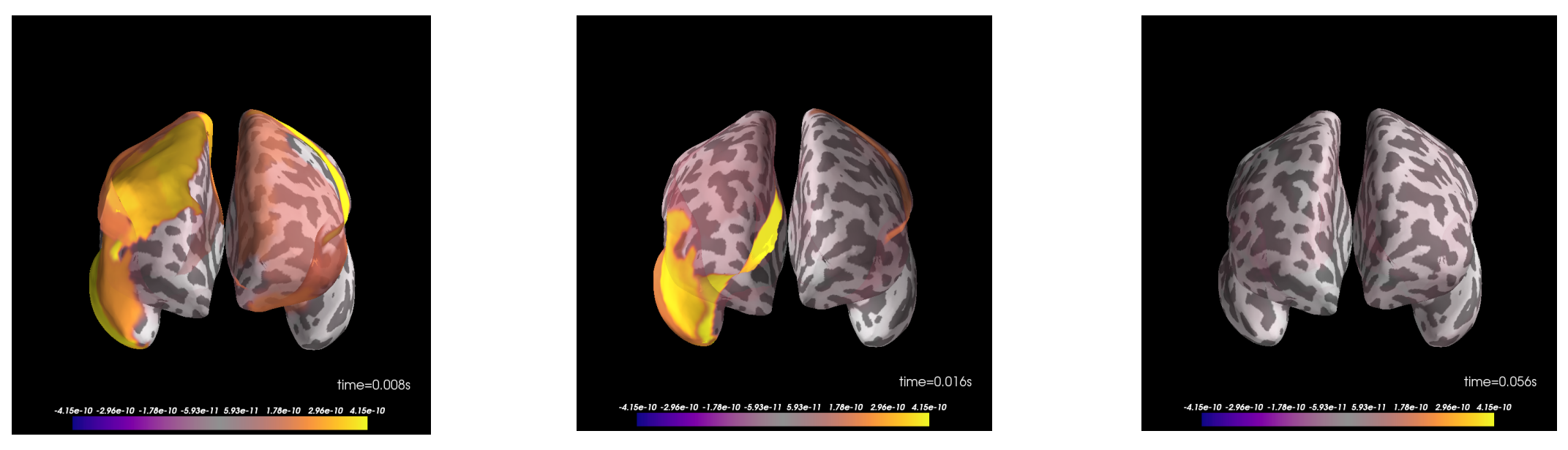


## 4. Results

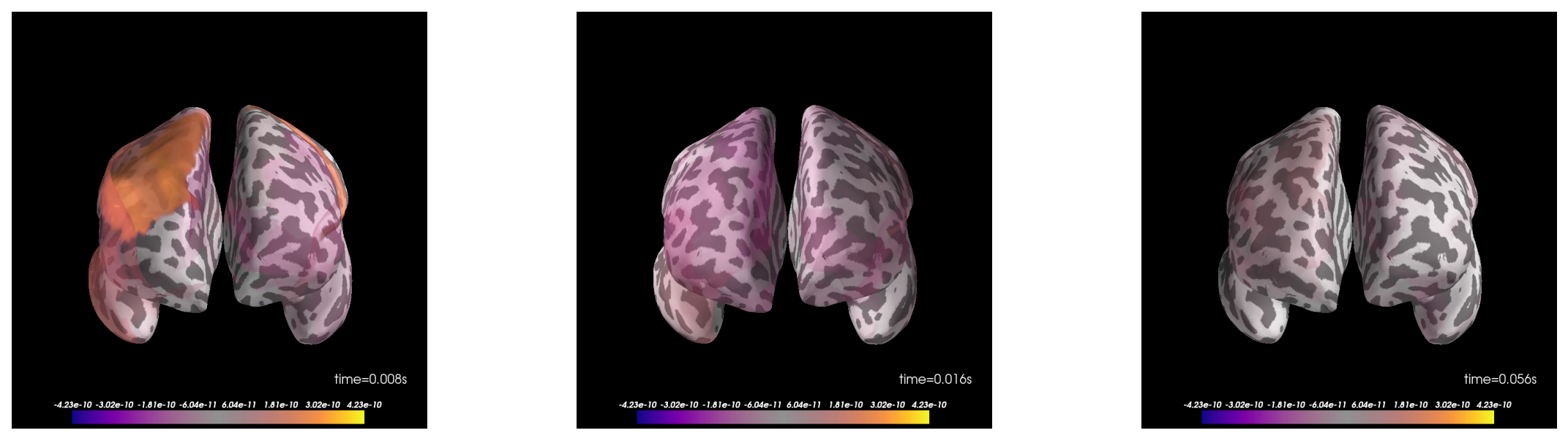
- Results of reconstruction of cortical activity from simulated MEG measurements are presented and compared to original LORETA method.

**t =0.008 s** **t = 0.016 s** **t = 0.056 s**

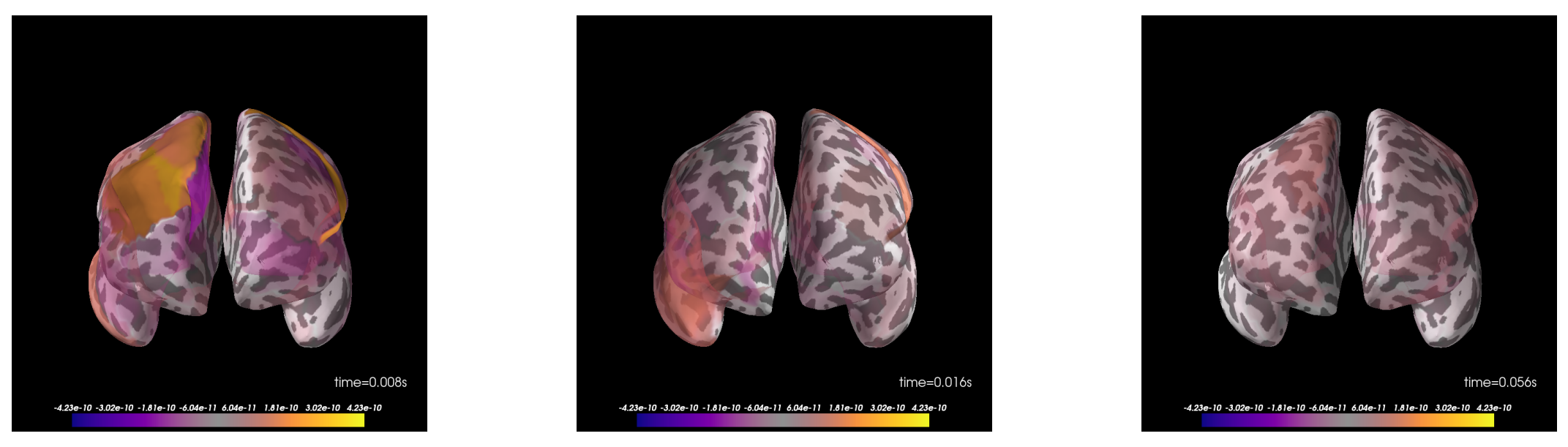
**Simulated cortical activities (gorund truth)**



**Reconstructed sources – original LORETA**



**Reconstructed sources – connectivity-informed LORETA**



## 5. Conclusion

- The preliminary results of MEG source reconstruction obtained using **simulated source activity** according to a **MAR model** and **spatio–temporal** approach for **inverse solution** were presented.

- We tackled the ill–posed problem in both space and time and obtained promising results in terms of amplitude and focality.

- Nevertheless, further simulations need to be performed with multiple subject in order to validate the preliminary results.

**Acknowledgments** – this work has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (ERC Advanced Grant agreement No 649665: CoBCoM – Computational Brain Connectivity Mapping)

**References:** [**1**] Baillet S., "Magnetoencephalography for brain electrophysiology and imaging", Nature Neuroscience, 2017. [**2**] Pascual-Marqui, R. D. et al. "Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain", International Journal of psychophysiology, 1994. [**3**] A. Gramfort et al. "Mne software for processing meg and eeg data", Neuroimage, 2014. [**4**] Van Essen, D. C. et al., "The wu-minn human connectome project: an overview", Neuroimage, 2013. [**5**] Desikan, R. S. et al. "An automated labeling system for subdividing the human cerebral cortex on mri scans into gyral based regions ofinterest", Neuroimage, 2006. [**6**] H. Lütkepohl, New introduction to multiple time series analysis. Springer Science & Business Media,2005.

**Colloque Line Garnero, October 8, 2019, Paris, France**