

# Statistical inference for Same Data Meta-Analysis (SDMA) for neuroimaging multiverse analyzes



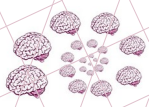
Jeremy  
Lefort-Besnard



Thomas  
Nichols

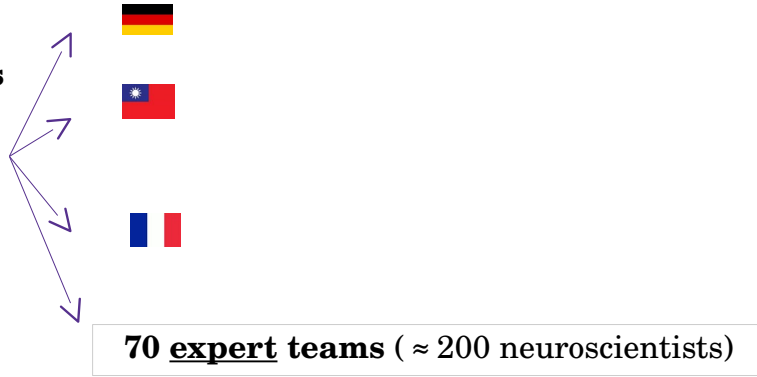
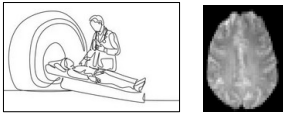


Camille  
Maumet

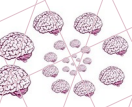


**NARPS study** (Rotem Botvinik-Nezer et al. Variability in the analysis of a single neuroimaging dataset by many teams. *Nature*, 2020)

SAME  
data & research questions

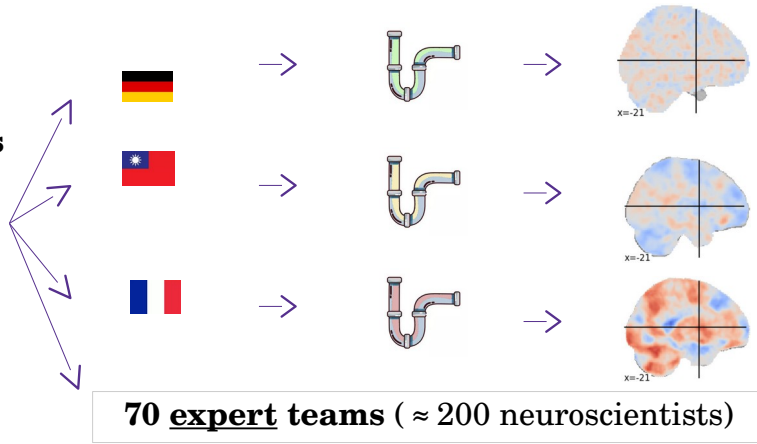
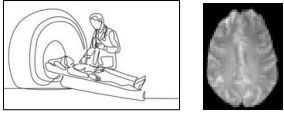


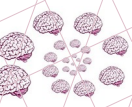
# Same Data Meta-Analysis - Introduction



**NARPS study** (Rotem Botvinik-Nezer et al. Variability in the analysis of a single neuroimaging dataset by many teams. *Nature*, 2020)

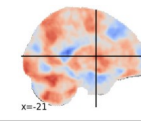
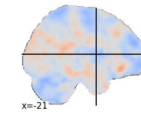
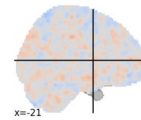
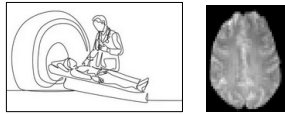
SAME  
data & research questions



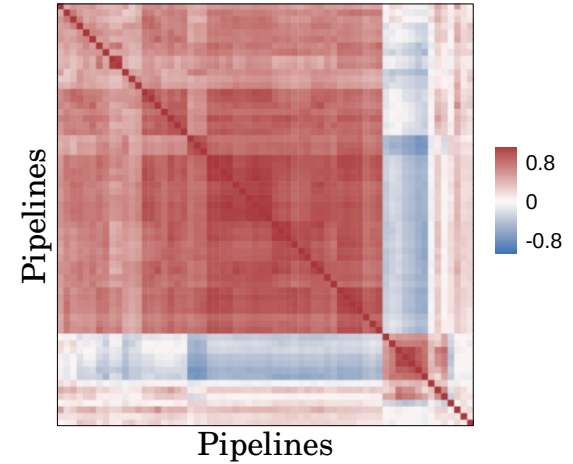


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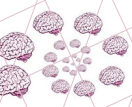
**SAME**  
data & research questions



**70 expert teams** (≈ 200 neuroscientists)

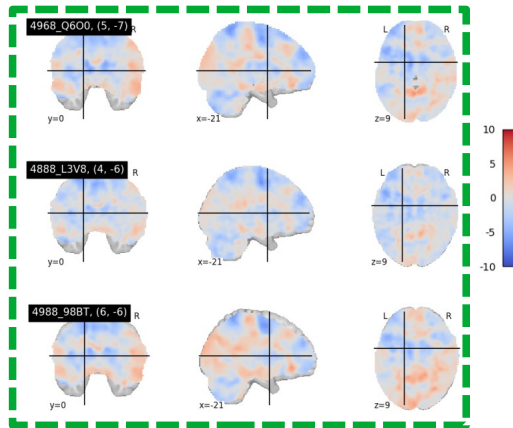
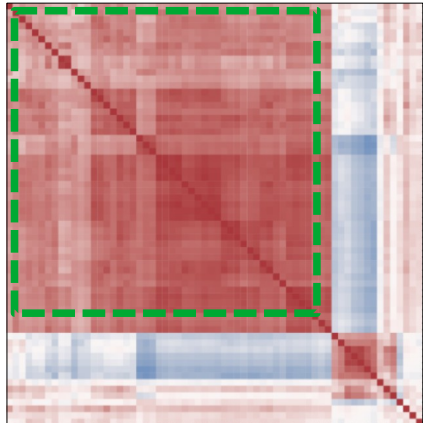
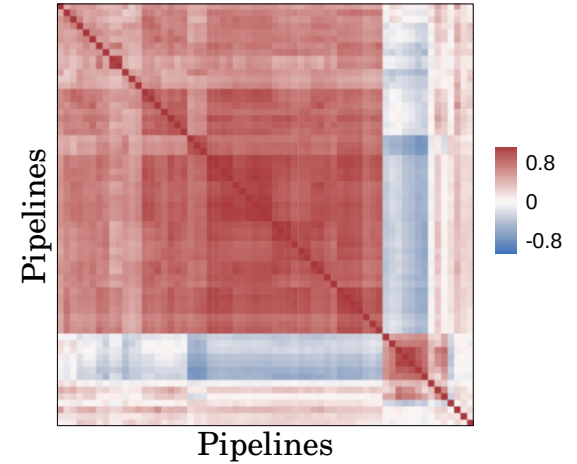
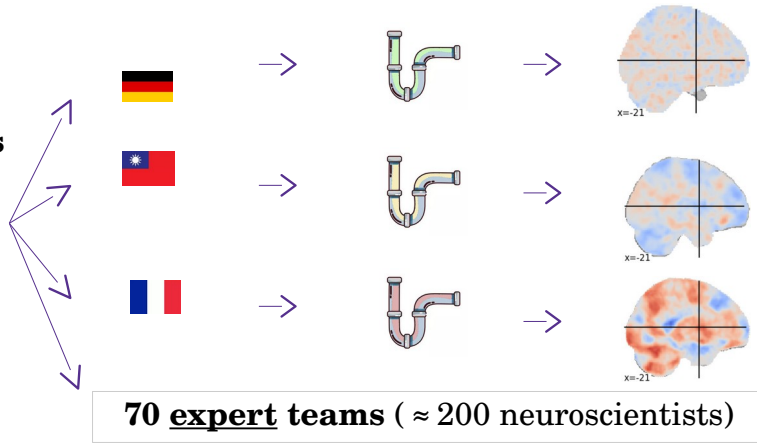
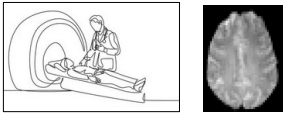


# Same Data Meta-Analysis - Introduction

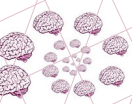


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**SAME**  
data & research questions

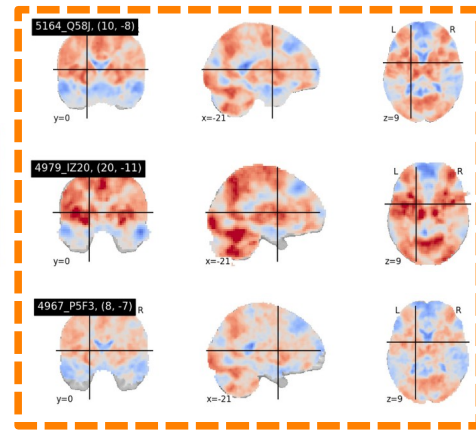
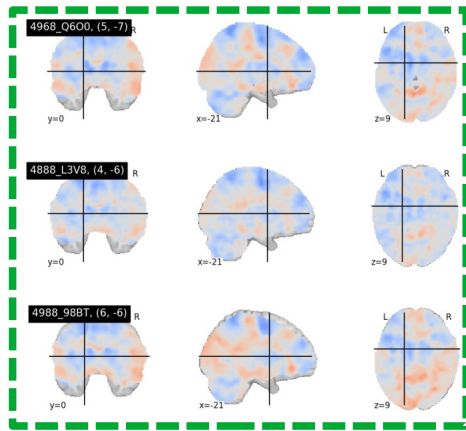
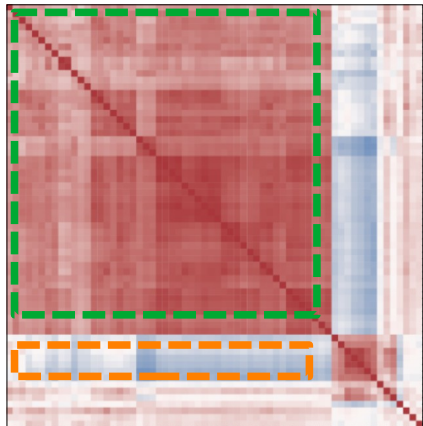
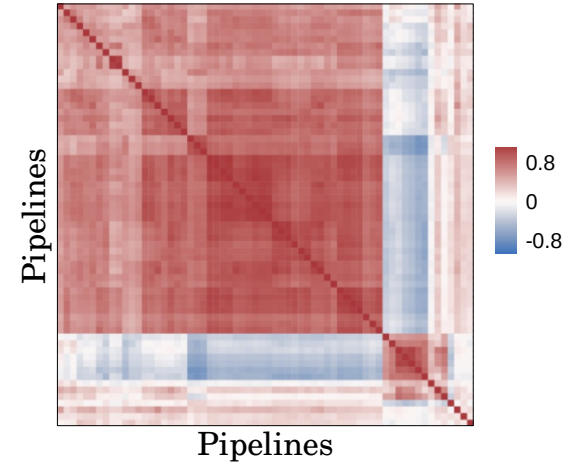
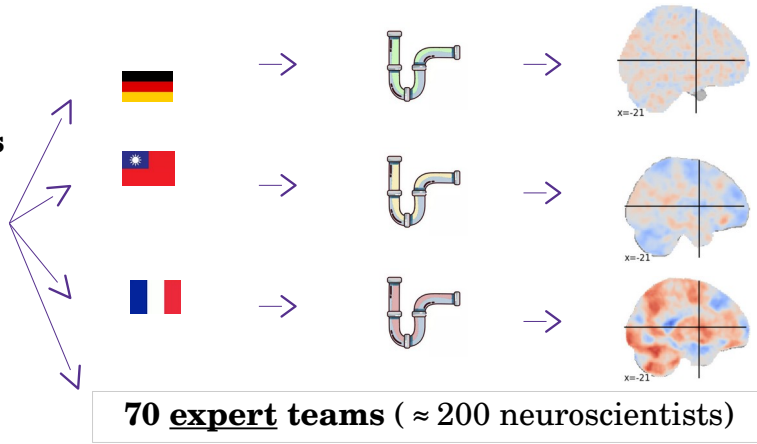
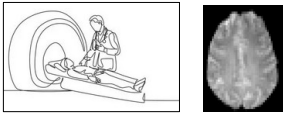


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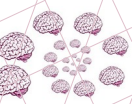


**NARPS study** (Rotem Botvinik-Nezer et al. Variability in the analysis of a single neuroimaging dataset by many teams. *Nature*, 2020)

**SAME**  
data & research questions

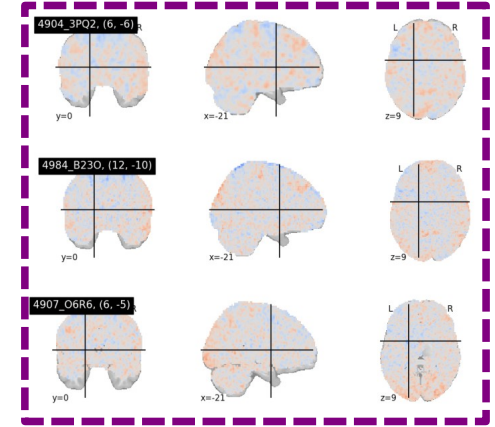
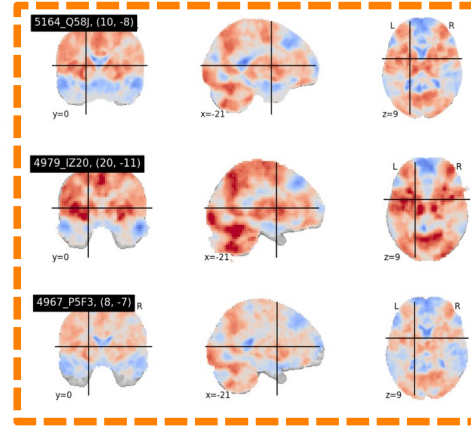
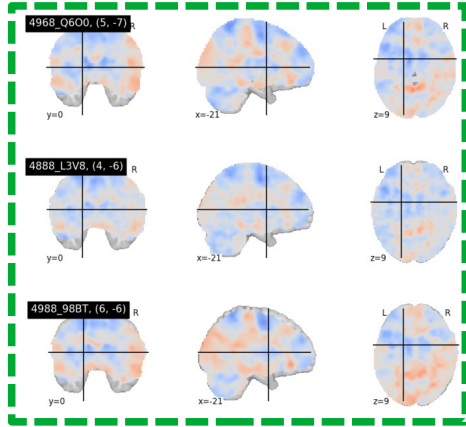
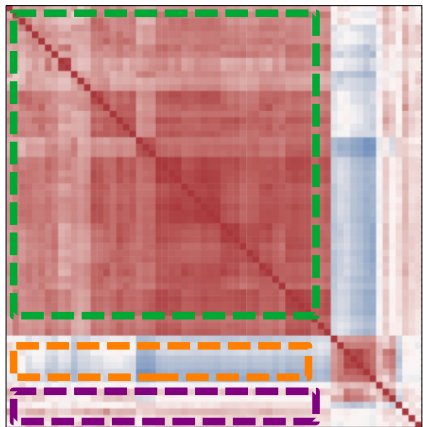
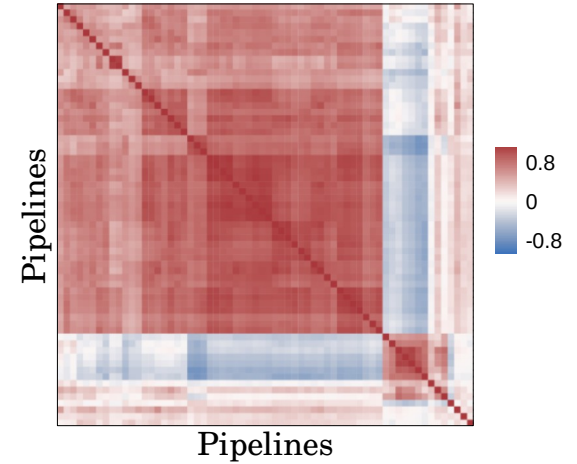
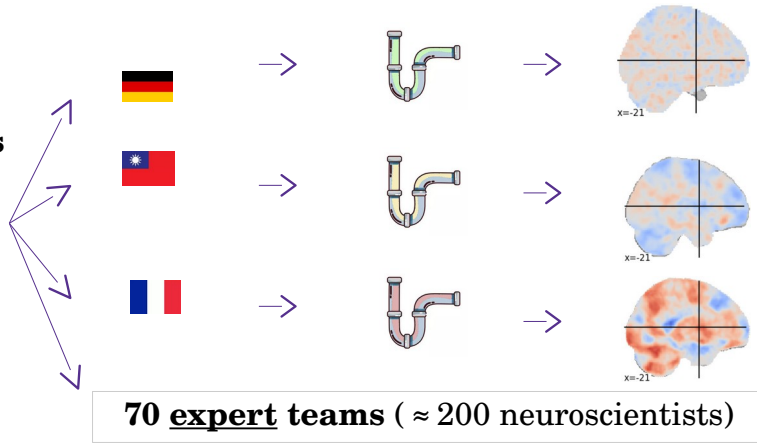
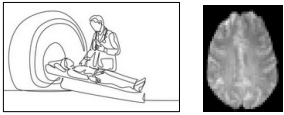


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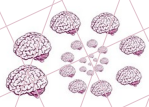


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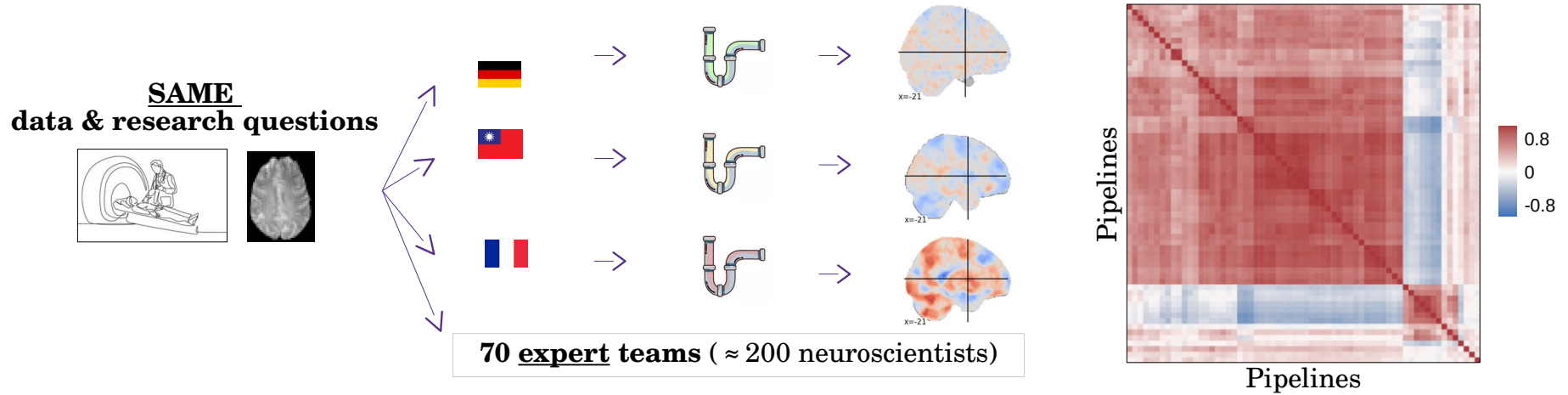
**SAME**  
data & research questions



# Same Data Meta-Analysis - Introduction

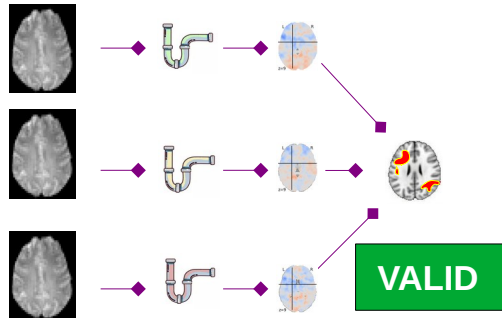


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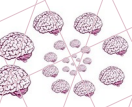
## Classical meta-analysis methods in :

### Traditional analysis setting

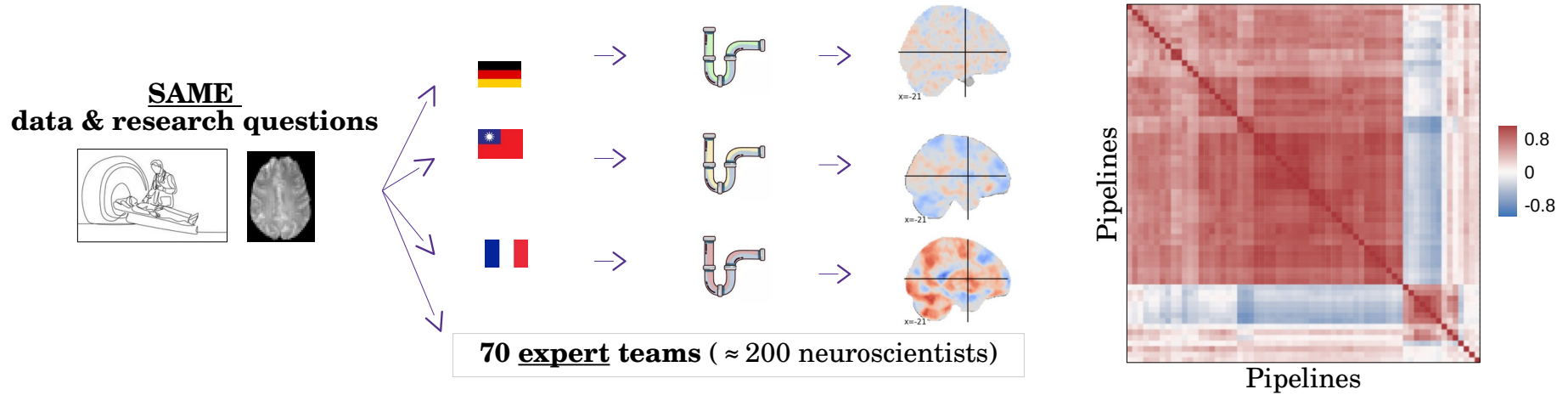




# Same Data Meta-Analysis - Introduction

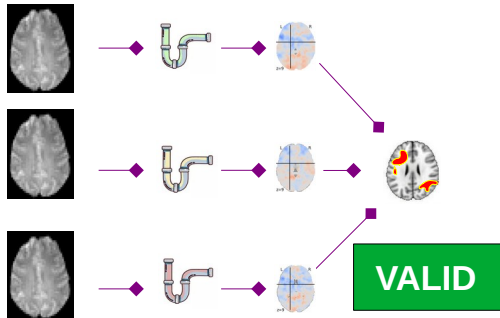


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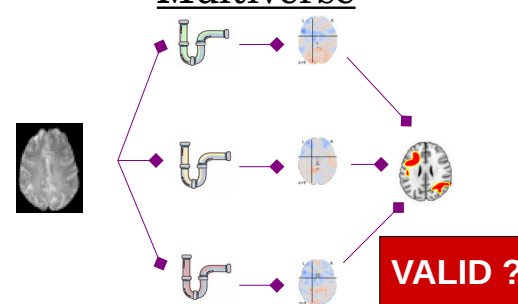


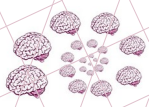
## Classical meta-analysis methods in :

### Traditional analysis setting



### Multiverse





## CLASSICAL Meta-Analysis

## SAME DATA Meta-Analysis

Stouffer

**SDMA  
Stouffer**

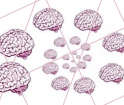
$$Z_j^S = \frac{\bar{Y}_j}{\sqrt{1/K}}$$

$$Z_j^{SS} = \frac{\bar{Y}_j}{\sqrt{\mathbf{1}_k^T \mathbf{Q} \mathbf{1}_k / K^2}}$$

Average standardized

Average standardized  
accounting for  
dependence

Lefort-Besnard, Nichols\* and Maumet\*. (2024). Statistical inference for Same Data Meta-Analysis for neuroimaging multiverse analyzes. *In prep.*



## CLASSICAL Meta-Analysis

## SAME DATA Meta-Analysis

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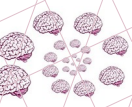
Average standardized  
accounting for  
dependence

**Consensus  
SDMA  
Stouffer**

$$Z_j^{CSS} = Z_j^{SS} - \langle Z^{SS} \rangle + \mu_C$$

Average standardized  
accounting for  
dependence,  
and shifted empirically

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## CLASSICAL Meta-Analysis

## SAME DATA Meta-Analysis

Stouffer

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Average standardized

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Stouffer**

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Average standardized  
accounting for  
dependence

**Consensus  
SDMA  
Stouffer**

$$Z_j^{CSS} = Z_j^{SS} - \langle Z^{SS} \rangle + \mu_C$$

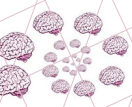
Average standardized  
accounting for  
dependence,  
and shifted empirically

**Consensus  
Average**

$$Z_j^{CA} = \frac{\bar{Y}_j - \langle \bar{Y} \rangle}{\sqrt{\langle \bar{Y} \rangle}} \sigma_C + \mu_C$$

Average, scaled  
and shifted empirically

Lefort-Besnard, Nichols\* and Maumet\*. (2024). Statistical inference for Same Data Meta-Analysis for neuroimaging multiverse analyzes. *In prep.*



## CLASSICAL Meta-Analysis

## SAME DATA Meta-Analysis

Stouffer

$$Z_j^S = \frac{\bar{Y}_j}{\sqrt{1/K}}$$

Average standardized

**SDMA  
Stouffer**

$$Z_j^{SS} = \frac{\bar{Y}_j}{\sqrt{\mathbf{1}_k^\top \mathbf{Q} \mathbf{1}_k / K^2}}$$

Average standardized  
accounting for  
dependence

**Consensus  
SDMA  
Stouffer**

$$Z_j^{CSS} = Z_j^{SS} - \langle Z^{SS} \rangle + \mu_C$$

Average standardized  
accounting for  
dependence,  
and shifted empirically

**Consensus  
Average**

$$Z_j^{CA} = \frac{\bar{Y}_j - \langle \bar{Y} \rangle}{\sqrt{\langle \bar{Y} \rangle}} \sigma_C + \mu_C$$

Average, scaled  
and shifted empirically

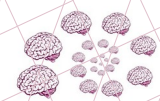
**SDMA GLS**

$$Z_j^{SG} = \frac{\mathbf{1}^\top \mathbf{Q}^{-1} \mathbf{Y}_j}{\sqrt{\mathbf{1}^\top \mathbf{Q}^{-1} \mathbf{1}}}$$

Optimal average,  
standardised

Lefort-Besnard, Nichols\* and Maumet\*. (2024). Statistical inference for Same Data Meta-Analysis for neuroimaging multiverse analyzes. *In prep.*

# Same Data Meta-Analysis - Results in simulations



## CLASSICAL Meta-Analysis

Stouffer

## SAME DATA Meta-Analysis

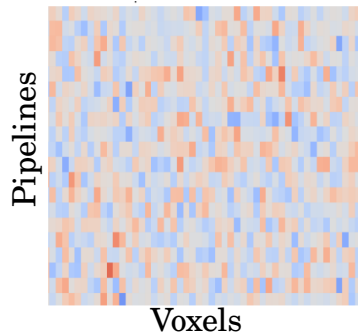
**SDMA  
Stouffer**

**Consensus  
SDMA  
Stouffer**

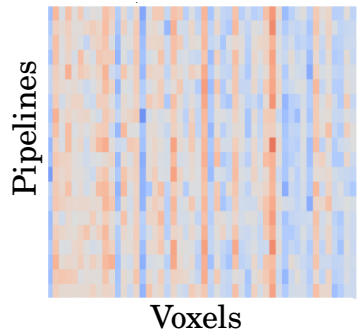
**Consensus  
Average**

**SDMA GLS**

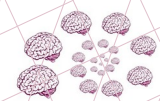
### Traditional



### Multiverse



# Same Data Meta-Analysis - Results in simulations



## CLASSICAL Meta-Analysis

Stouffer

## SAME DATA Meta-Analysis

**SDMA  
Stouffer**

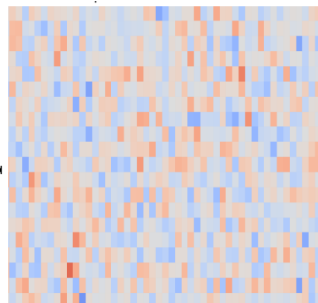
**Consensus  
SDMA  
Stouffer**

**Consensus  
Average**

**SDMA GLS**

### Traditional

Pipelines



Voxels

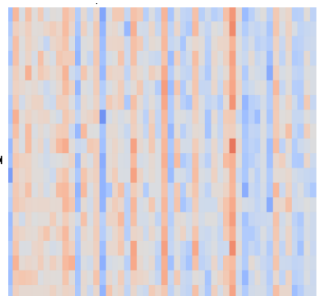
**VALID**

4.7 %

$\alpha = 5\%$  nominal

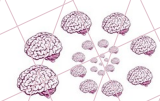
### Multiverse

Pipelines



Voxels

# Same Data Meta-Analysis - Results in simulations



## CLASSICAL Meta-Analysis

Stouffer

## SAME DATA Meta-Analysis

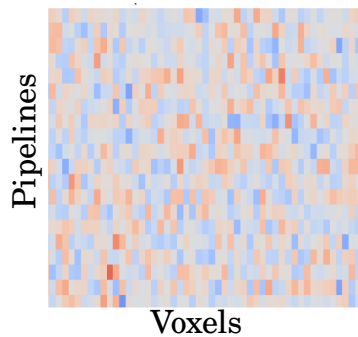
**SDMA  
Stouffer**

**Consensus  
SDMA  
Stouffer**

**Consensus  
Average**

**SDMA GLS**

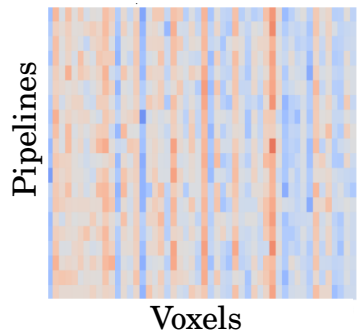
### Traditional



**VALID**  
4.7 %

$\alpha = 5\%$  nominal

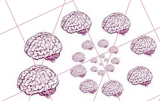
### Multiverse

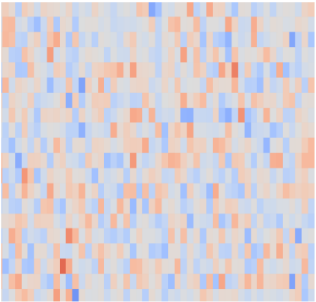
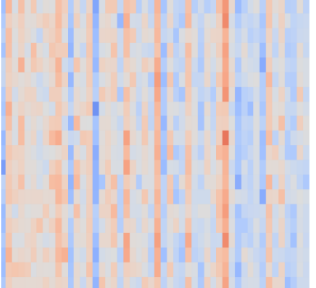


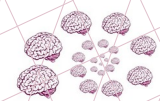
**INVALID**  
30.1 %



# Same Data Meta-Analysis - Results in simulations



		CLASSICAL Meta-Analysis	SAME DATA Meta-Analysis			
		Stouffer	SDMA Stouffer	Consensus SDMA Stouffer	Consensus Average	SDMA GLS
<b>Traditional</b>						
Pipelines		<b>VALID</b> 4.7 %	<b>VALID</b> 4.7 %	<b>VALID</b> 4.8 %	<b>VALID</b> 4.8 %	<b>VALID</b> 4.4 %
	Voxels	$\alpha = 5\%$ nominal				
<b>Multiverse</b>						
Pipelines		<b>INVALID</b> 30.1 %	<b>VALID</b> 4.9 %	<b>VALID</b> 5.0 %	<b>VALID</b> 5.0 %	<b>VALID</b> 4.9 %
	Voxels					



## SAME DATA Meta-Analysis

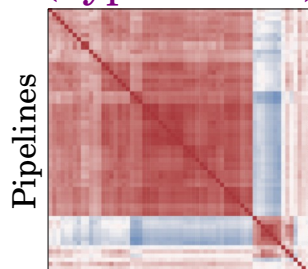
**SDMA  
Stouffer**

**Consensus  
SDMA  
Stouffer**

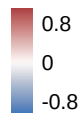
**Consensus  
Average**

**SDMA GLS**

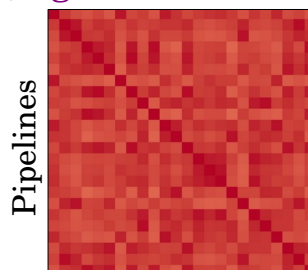
**NARPS  
(hypothesis 1)**



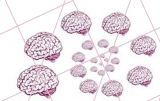
Pipelines



**HCP Young Adult  
(Right hand contrast)**



Pipelines



## SAME DATA Meta-Analysis

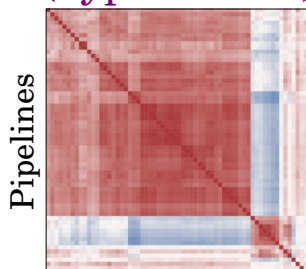
**SDMA  
Stouffer**

**Consensus  
SDMA  
Stouffer**

**Consensus  
Average**

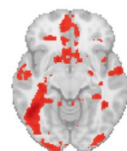
**SDMA GLS**

**NARPS  
(hypothesis 1)**

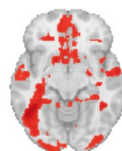


Pipelines

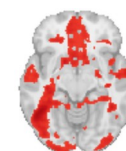
Pipelines



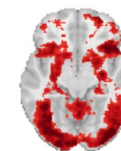
9.1 %



11.0 %

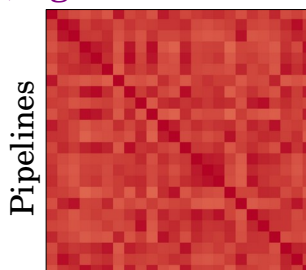


14.1 %



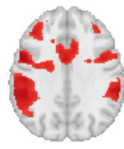
48.3 %

**HCP Young Adult  
(Right hand contrast)**



Pipelines

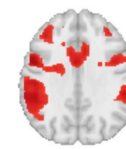
Pipelines



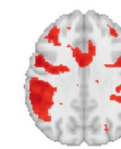
29.1 %



28.2 %

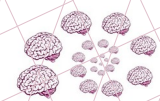


28.3 %



31.3 %

$P \leq 0.05$  (uncorrected)



## SAME DATA Meta-Analysis

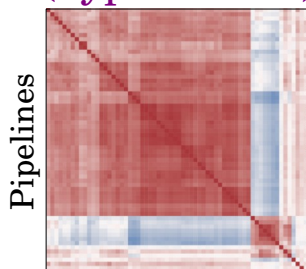
**SDMA  
Stouffer**

**Consensus  
SDMA  
Stouffer**

**Consensus  
Average**

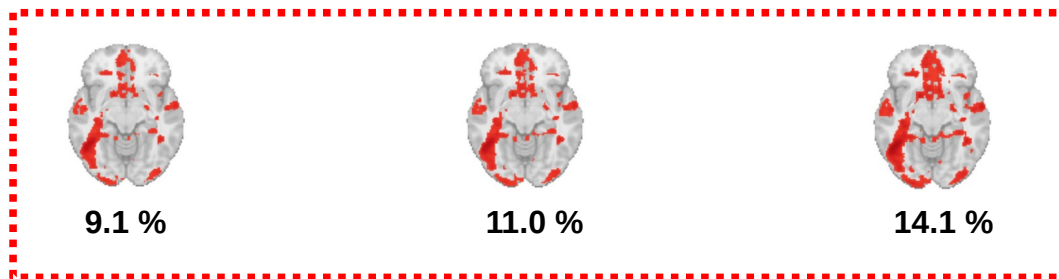
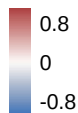
**SDMA GLS**

**NARPS  
(hypothesis 1)**



Pipelines

Pipelines



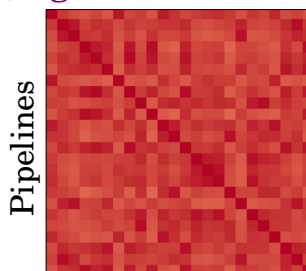
9.1 %

11.0 %

14.1 %

48.3 %

**HCP Young Adult  
(Right hand contrast)**



Pipelines

Pipelines



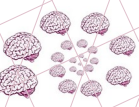
29.1 %

28.2 %

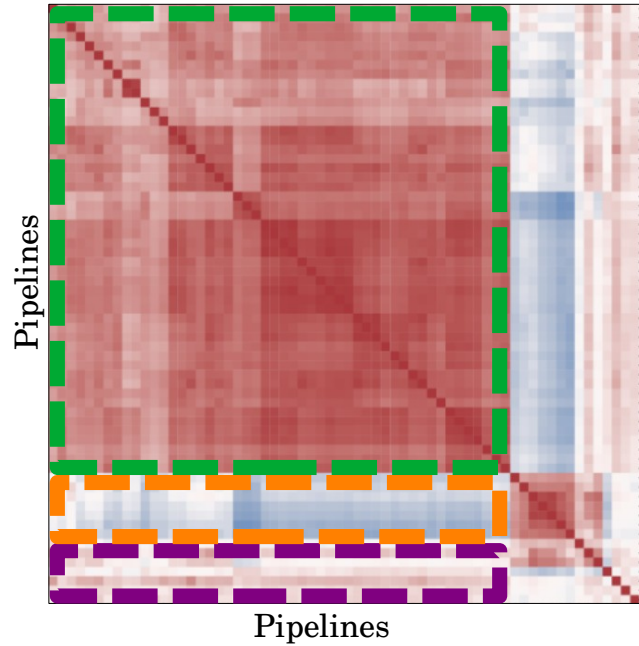
28.3 %

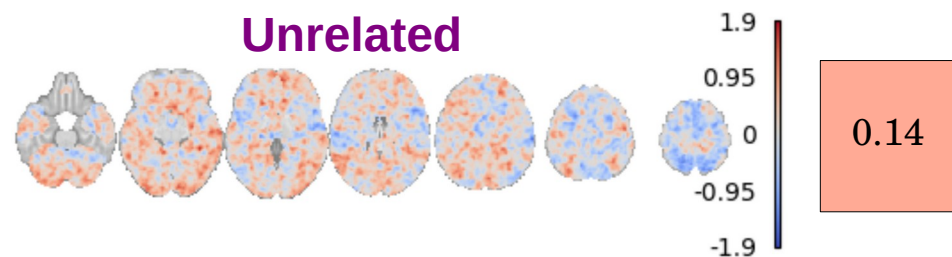
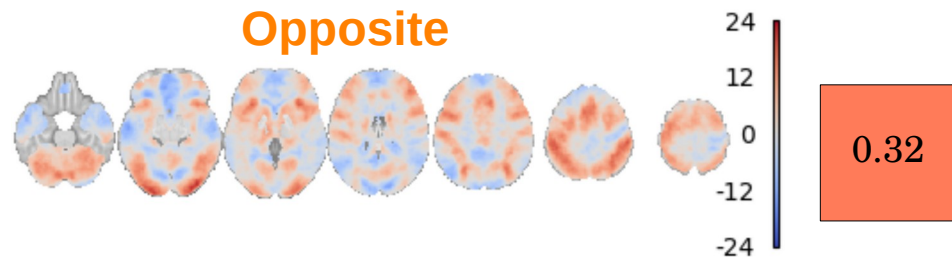
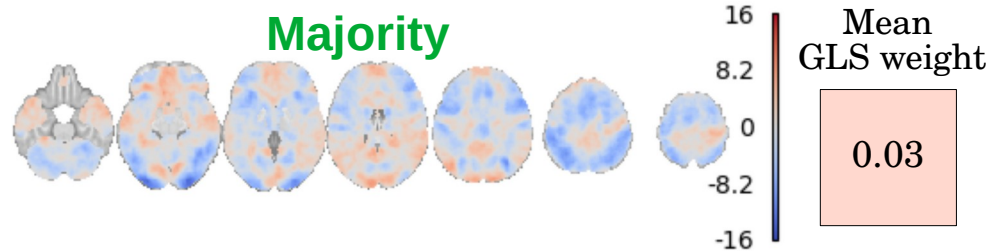
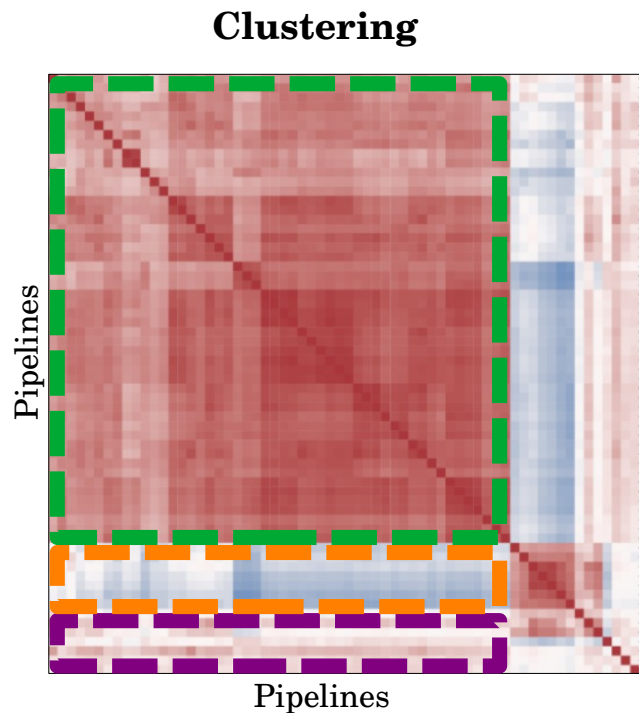
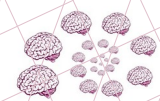
31.3 %

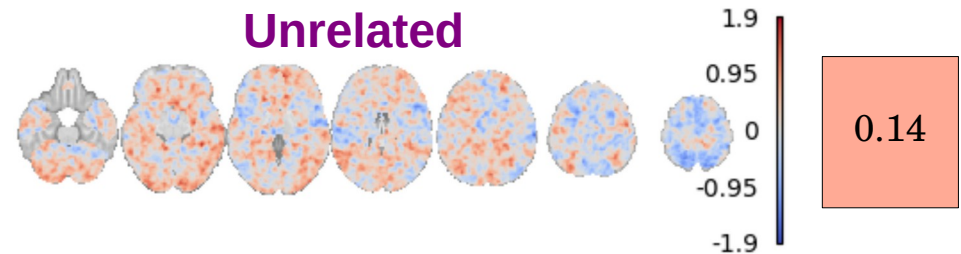
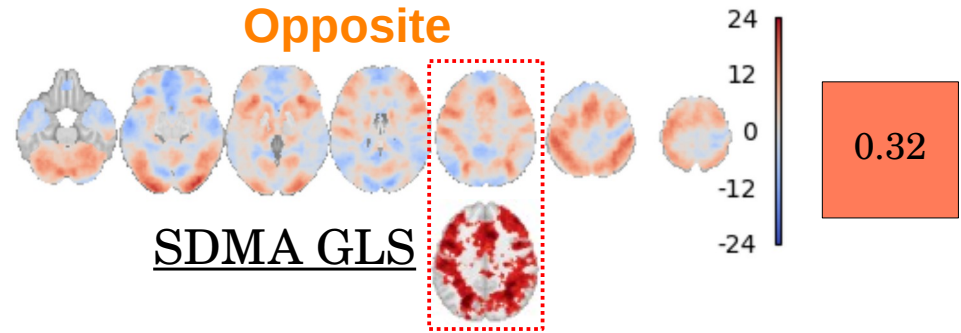
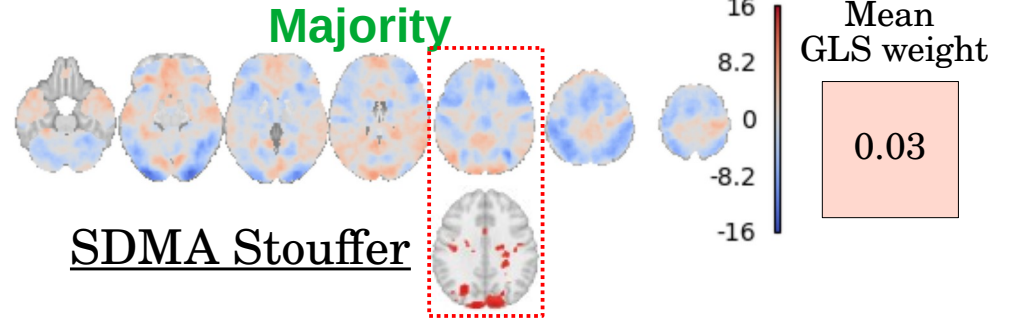
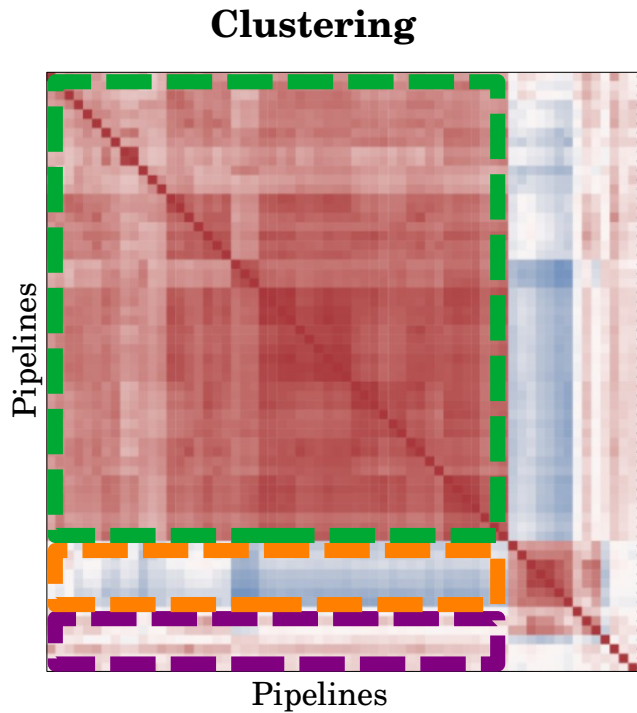
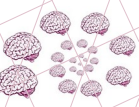
$P \leq 0.05$  (uncorrected)

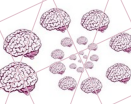


## Clustering









## Take-home message:

### **SDMA Stouffer**

$$Z_j^{SS} = \frac{\bar{Y}_j}{\sqrt{\mathbf{1}_k^\top \mathbf{Q} \mathbf{1}_k / K^2}}$$

Average standardized  
accounting for  
dependence

### **Consensus SDMA Stouffer**

$$Z_j^{CSS} = Z_j^{SS} - \langle Z^{SS} \rangle + \mu_C$$

Average standardized  
accounting for  
dependence,  
and shifted empirically

**Stable**

### **Consensus Average**

$$Z_j^{CA} = \frac{\bar{Y}_j - \langle \bar{Y} \rangle}{\sqrt{\langle \langle \bar{Y} \rangle \rangle}} \sigma_C + \mu_C$$

Average, scaled  
and shifted empirically

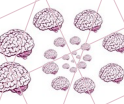
### **SDMA GLS**

$$Z_j^{SG} = \frac{\mathbf{1}^\top \mathbf{Q}^{-1} \mathbf{Y}_j}{\sqrt{\mathbf{1}^\top \mathbf{Q}^{-1} \mathbf{1}}}$$

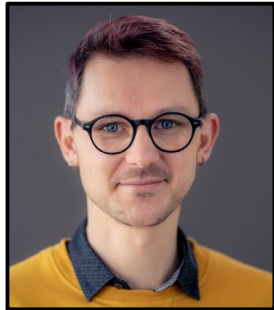
Optimal average,  
standardised

**Though theoretically  
optimal, unstable in  
heterogenous sample**





# Thank you !



Jeremy  
Lefort-Besnard



Thomas  
Nichols



Camille  
Maumet