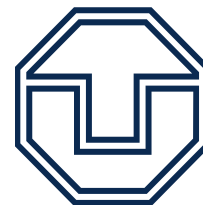


# Dynamic Causal Modelling for EEG and MEG

Stefan Kiebel



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# Overview

1 M/EEG analysis

2 Dynamic Causal Modelling – Motivation

3 Dynamic Causal Modelling – Generative model

4 Bayesian inference

5 Applications

# Overview

**1 M/EEG analysis**

2 Dynamic Causal Modelling – Motivation

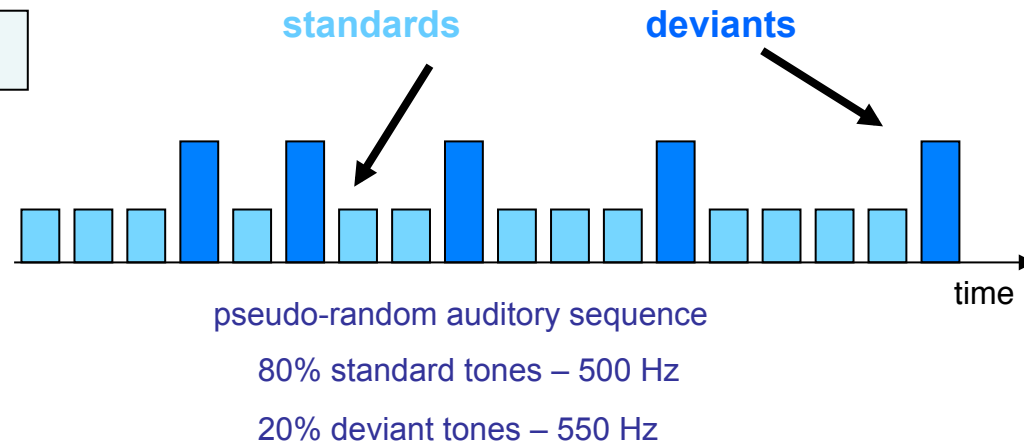
3 Dynamic Causal Modelling – Generative model

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5 Applications

# Mismatch negativity (MMN)

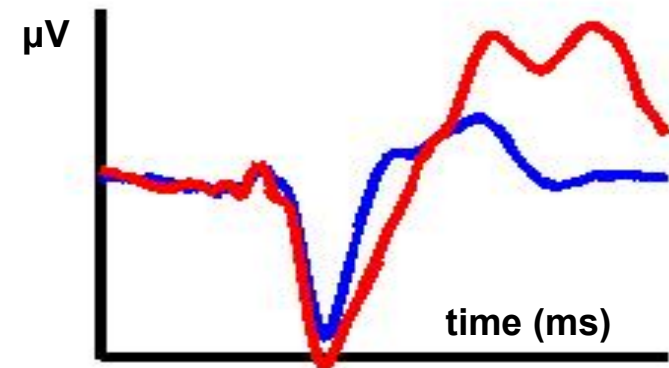
Paradigm



Raw data  
(e.g., 128 sensors)

Preprocessing  
(Statistical  
Parametric  
Mapping)

Evoked responses  
(shown: single sensor)



# Overview

1 M/EEG analysis

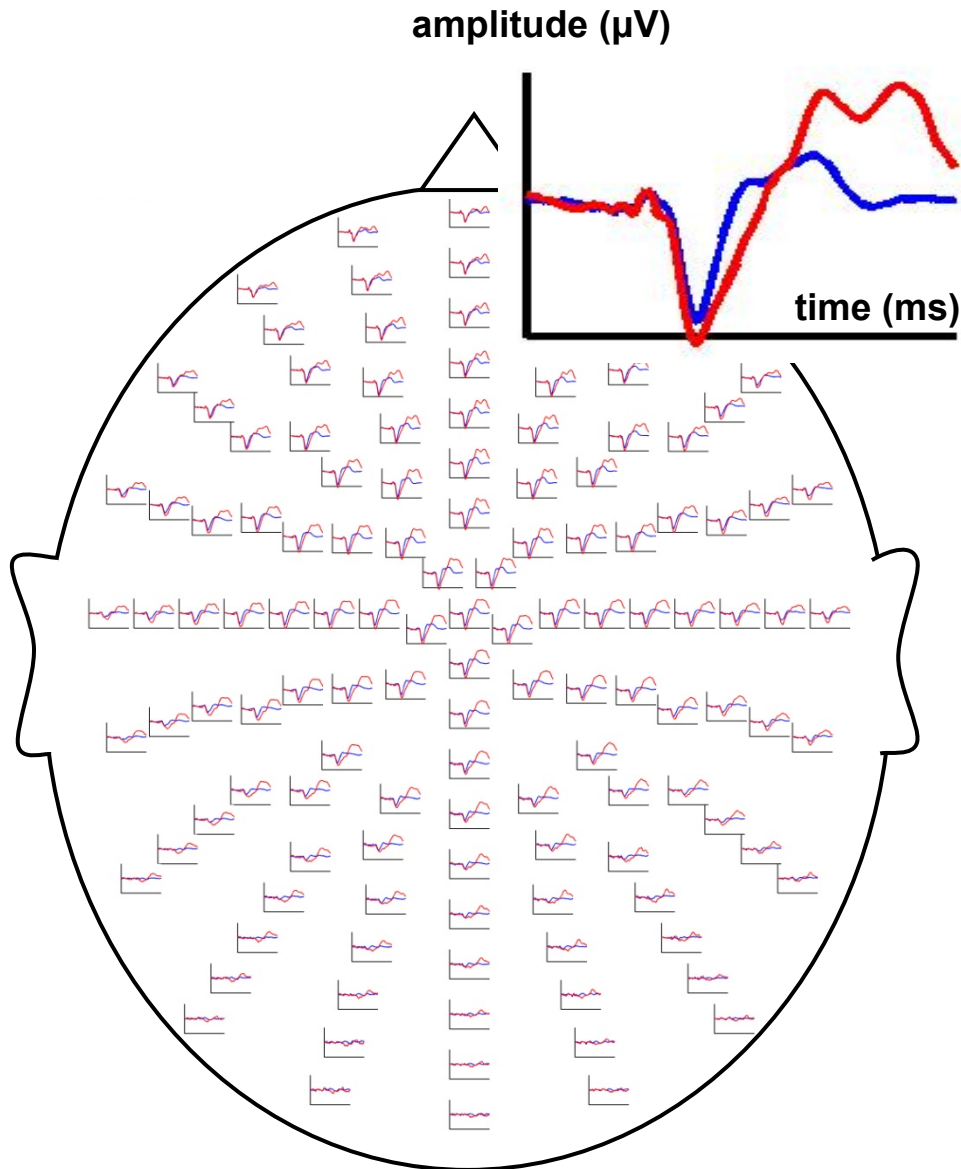
**2 Dynamic Causal Modelling – Motivation**

3 Dynamic Causal Modelling – Generative model

4 Bayesian inference

5 Applications

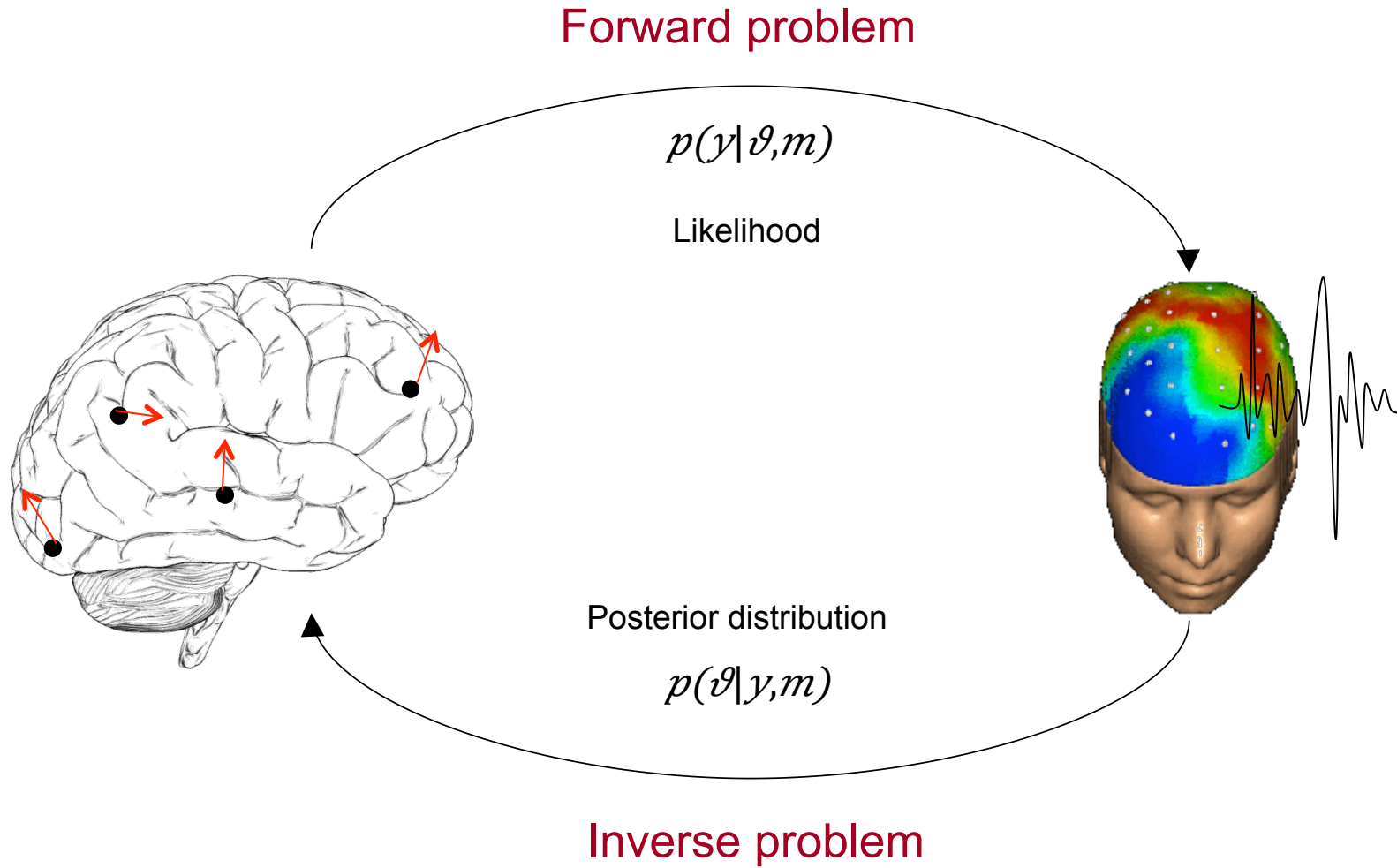
# Electroencephalography (EEG)



Modelling aim:  
Explain **all** data with few  
parameters

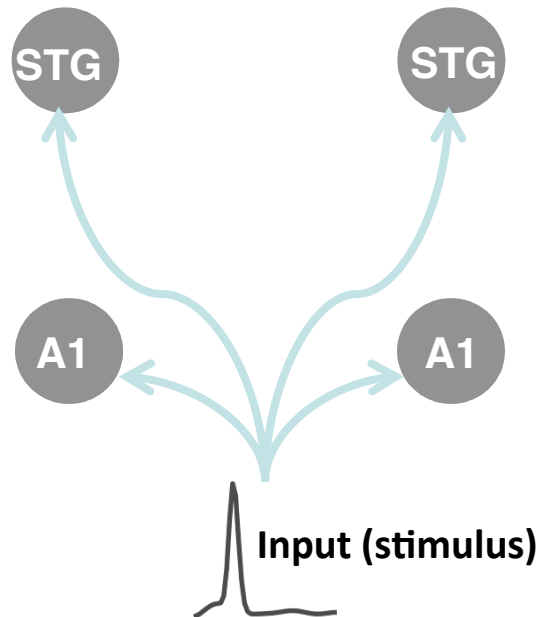
How to:  
Assume data are caused  
by few interacting brain  
sources

# Probabilistic inference

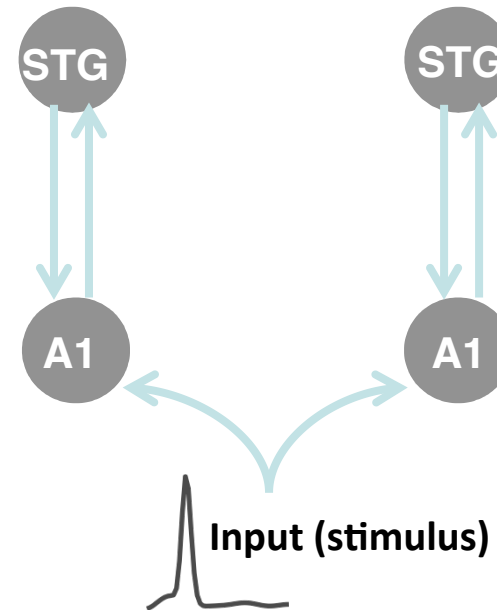


# Cognitive neuroscience

**Conventional analysis:  
Which regions are involved in task?**



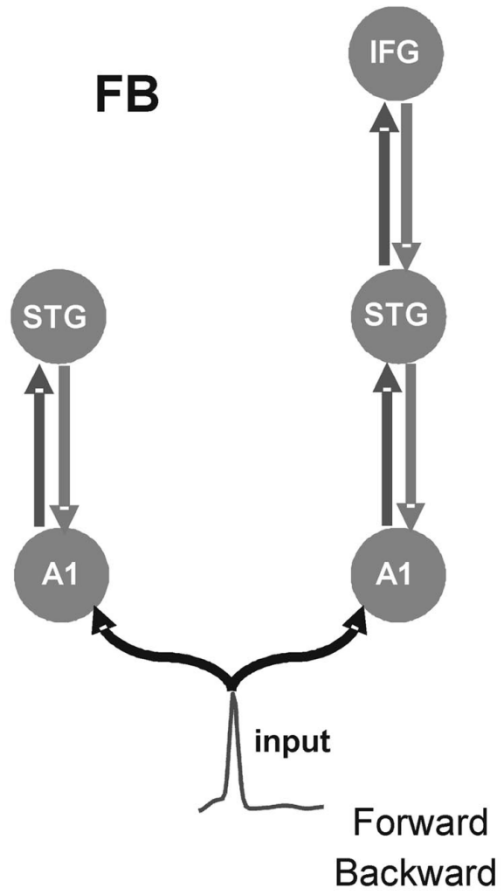
**DCM analysis:  
How do regions communicate?**



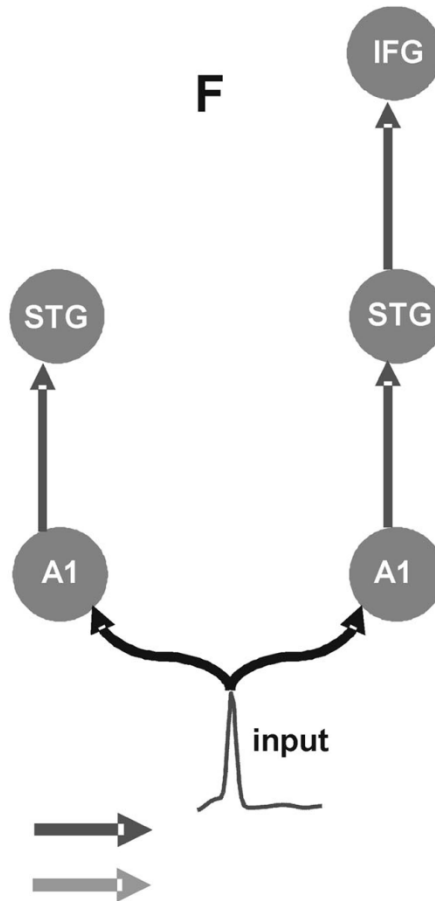


# Model for auditory evoked response

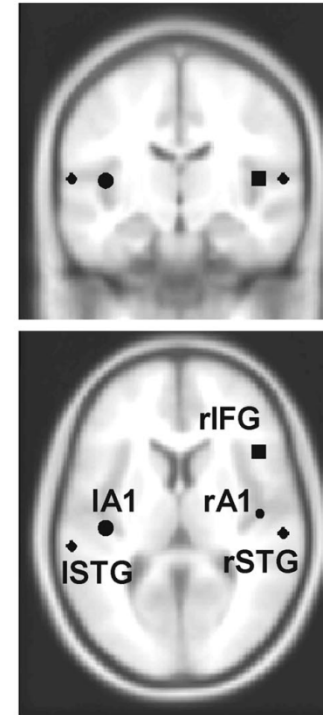
**A**  
with backward connections



**B**  
and without



**C**



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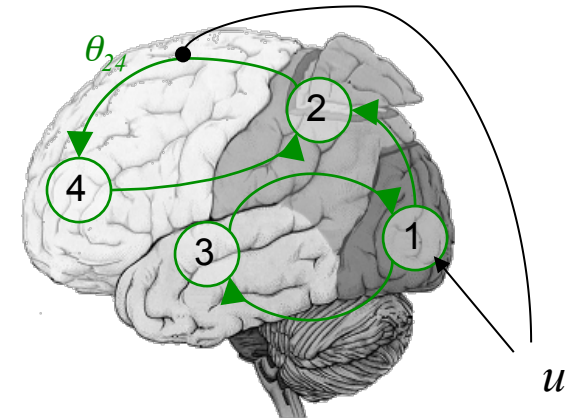
# The DCM approach

- DCM: model structure

$$\begin{cases} y = g(x, \varphi) + \varepsilon \\ \dot{x} = f(x, u, \theta) \end{cases}$$

likelihood

$$\Rightarrow p(y|\theta, \varphi, m)$$



- DCM: Bayesian inference

parameter estimate:

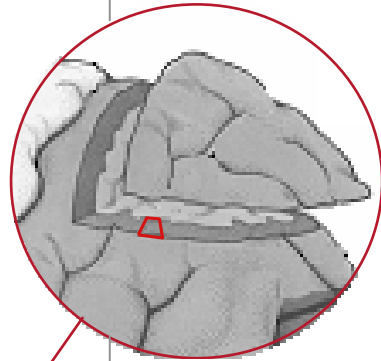
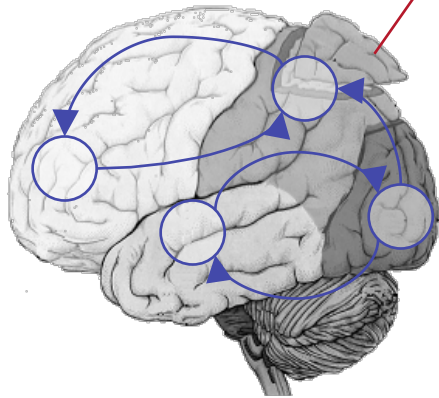
$$\hat{\theta} = E[\theta|y, m]$$

model evidence:

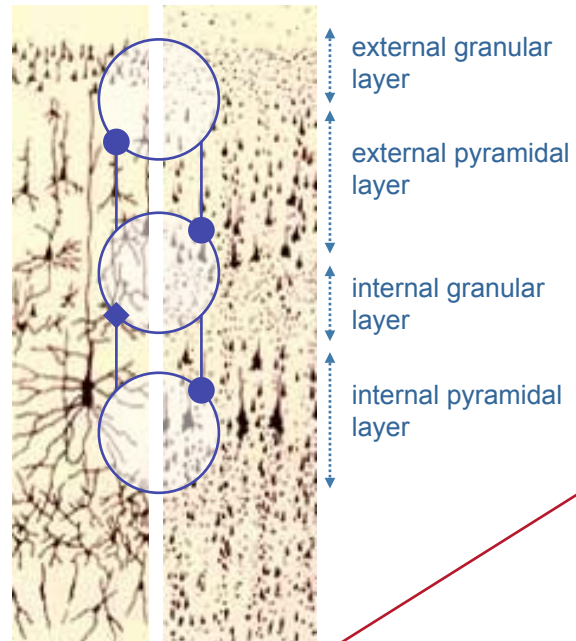
$$p(y|m) = \int p(y|\theta, \varphi, m) \overset{\text{priors on parameters}}{p(\theta|m) p(\varphi|m)} d\varphi d\theta$$

# Inference at meso-scale

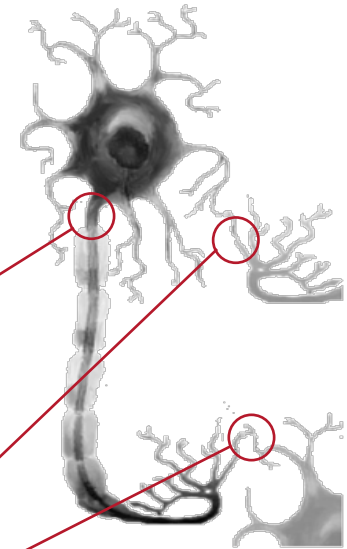
macro-scale



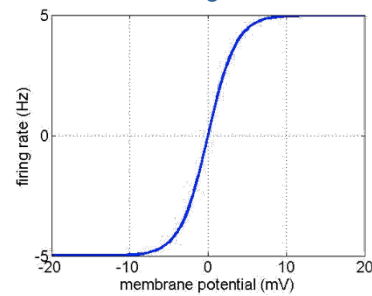
meso-scale



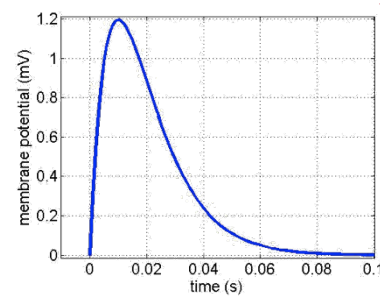
micro-scale



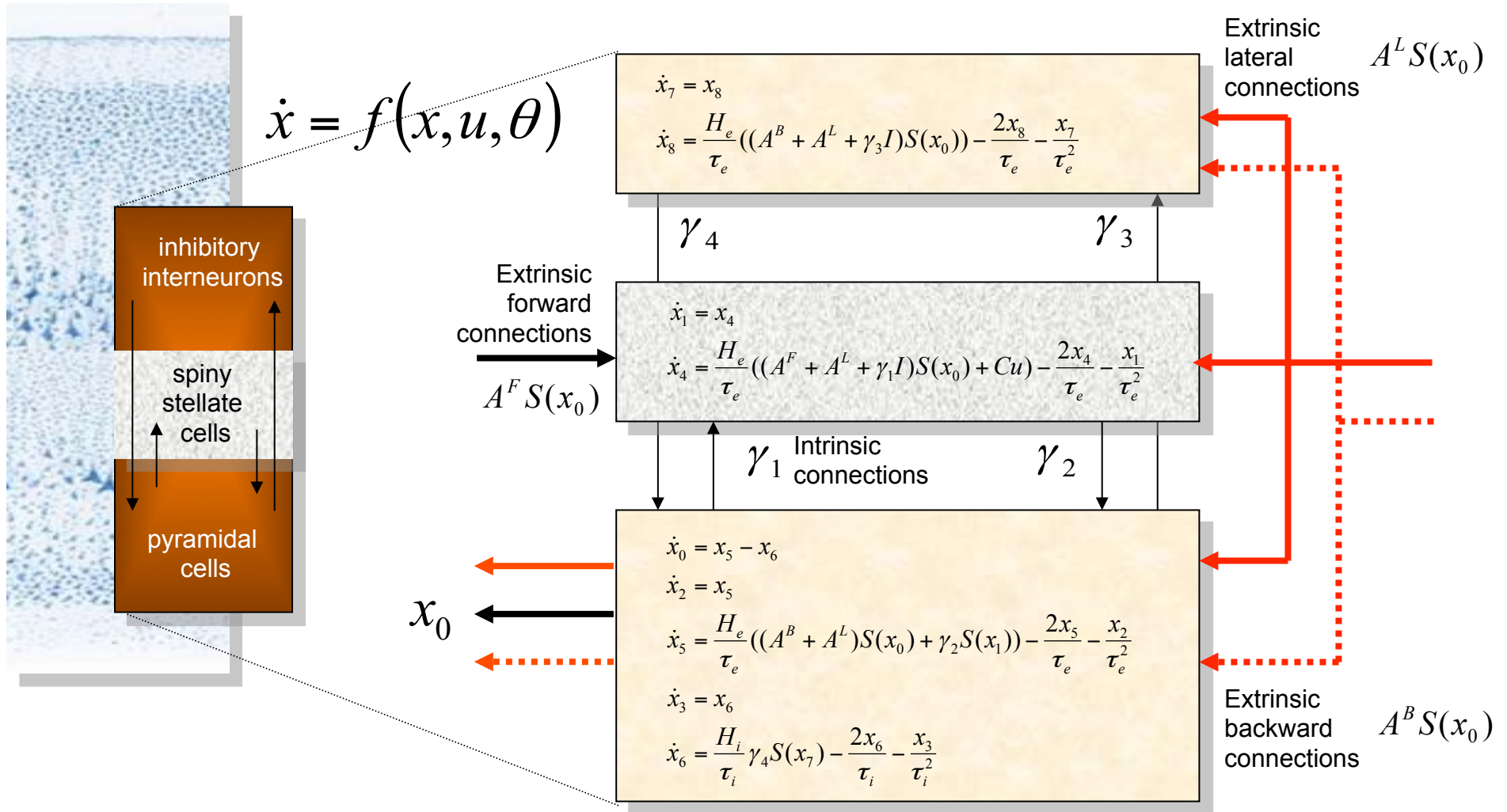
Firing rate



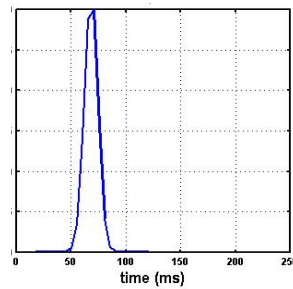
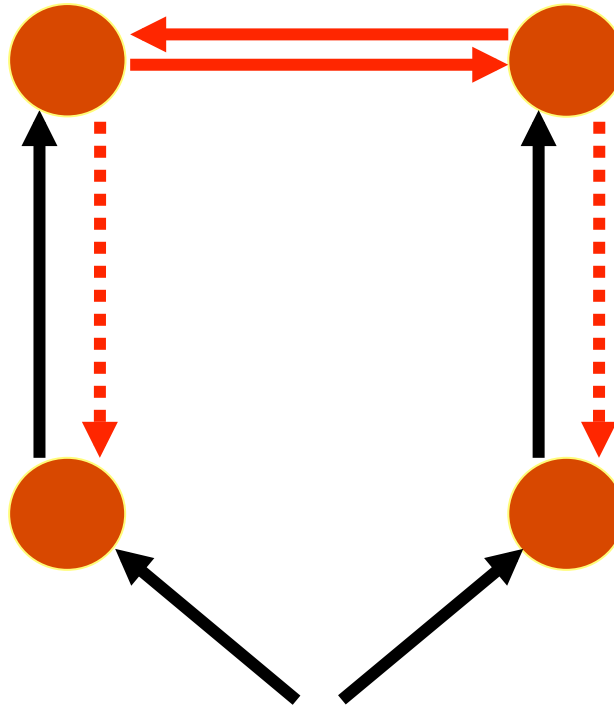
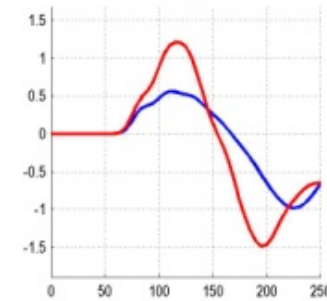
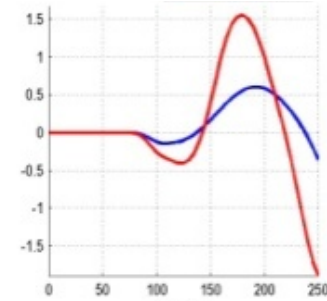
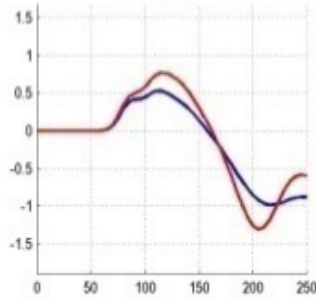
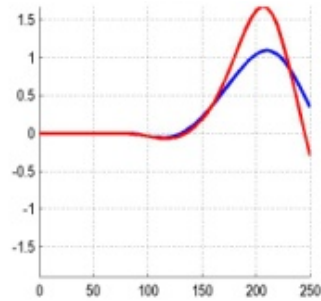
Synaptic dynamics



# Neural mass equations and connectivity



# Source activity over time



Input  $u$

Forward

Backward

Lateral

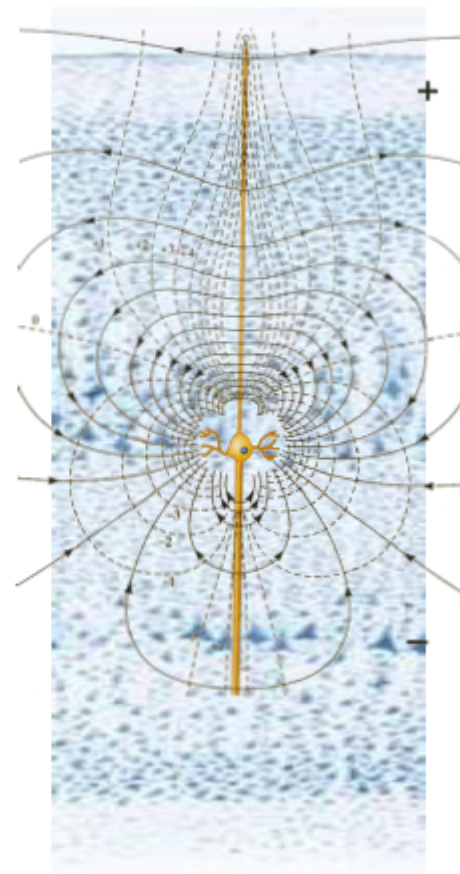
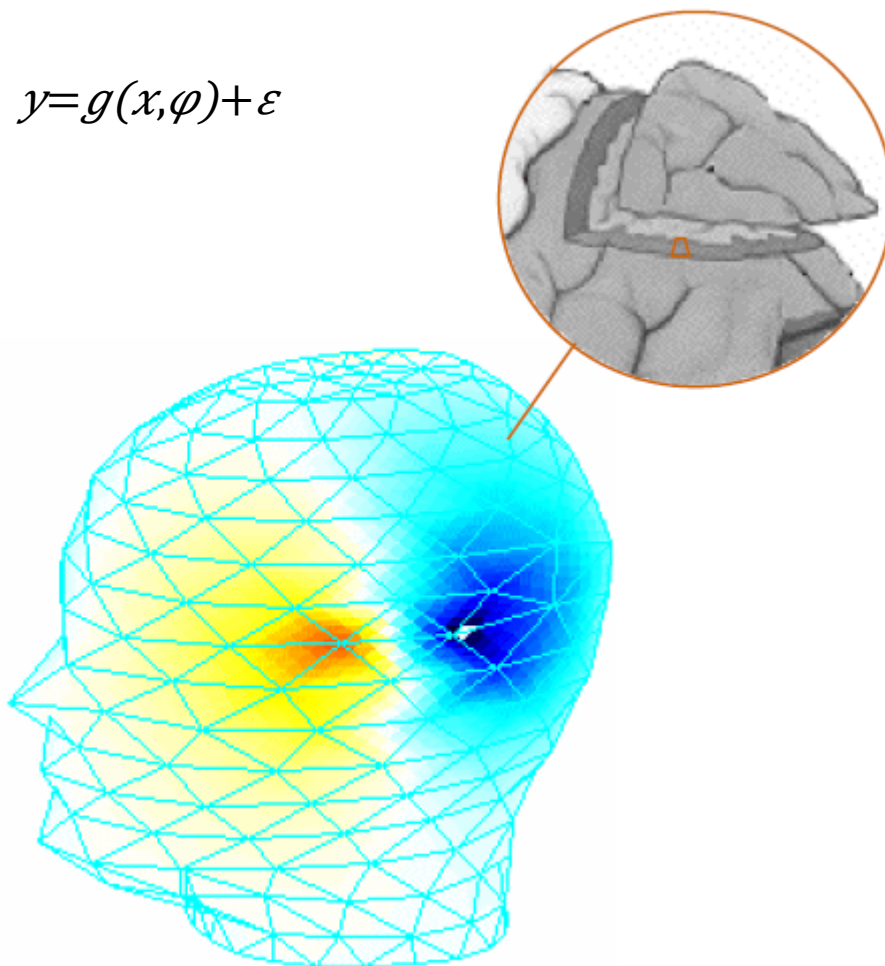
$$\dot{x} = f(x, u, \theta)$$

states  $x$

parameters  $\theta$

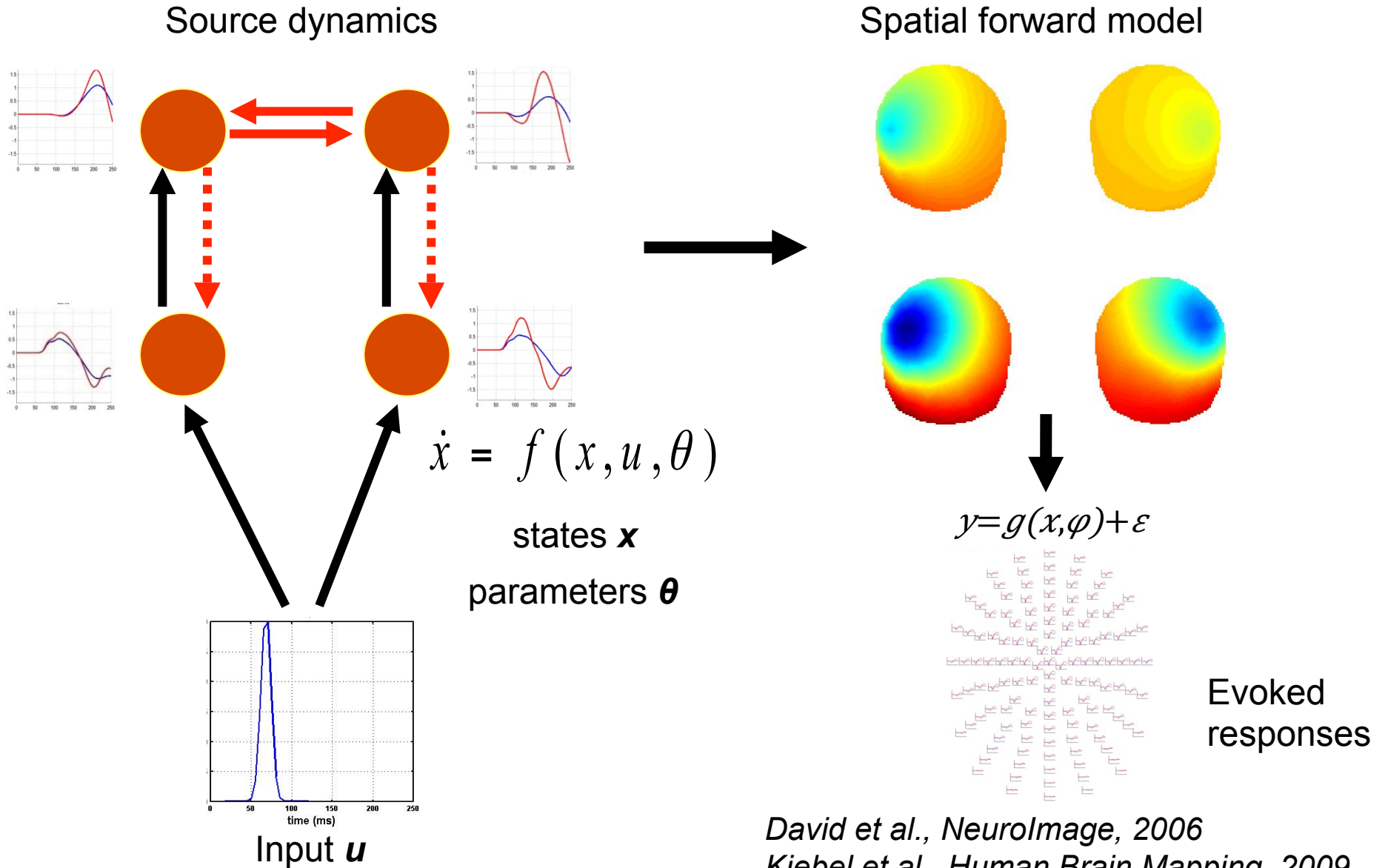
# Spatial forward model

$$y = g(x, \varphi) + \varepsilon$$



*Kiebel et al., NeuroImage, 2006*  
*Daunizeau et al., NeuroImage, 2009*

# The generative model





# Overview

1 M/EEG analysis

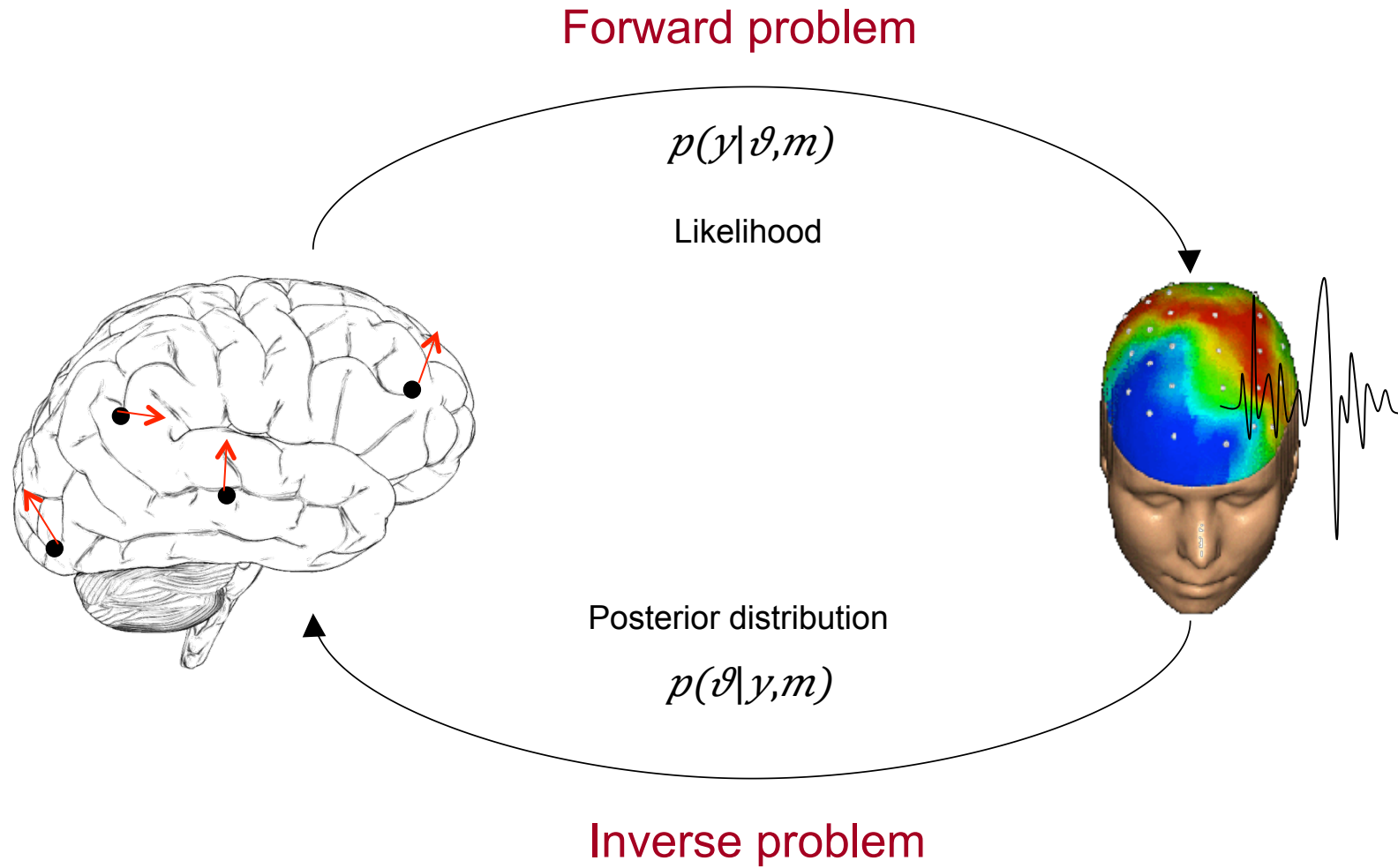
2 Dynamic Causal Modelling – Motivation

3 Dynamic Causal Modelling – Generative model

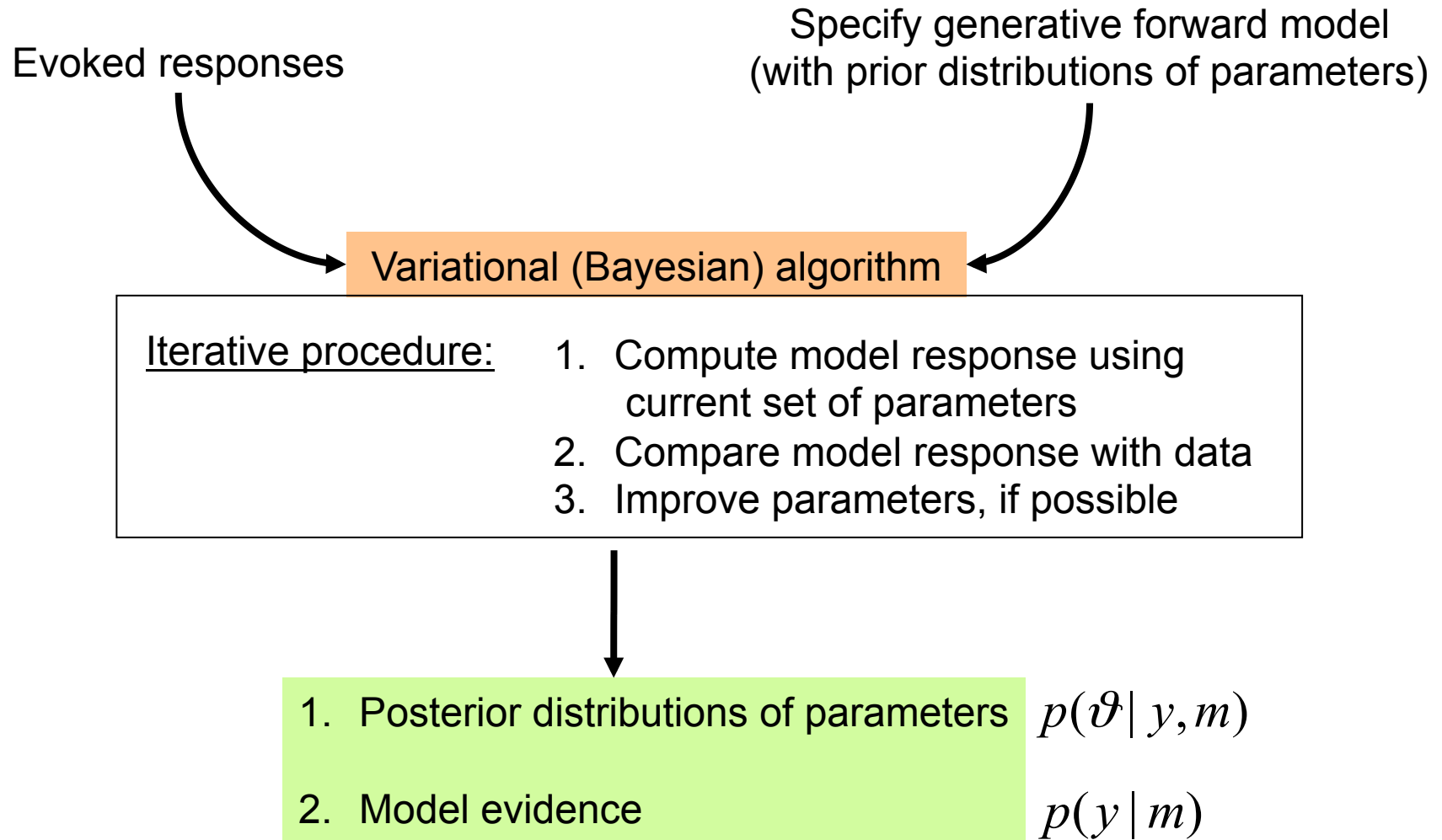
**4 Bayesian inference**

5 Applications

# Probabilistic inference

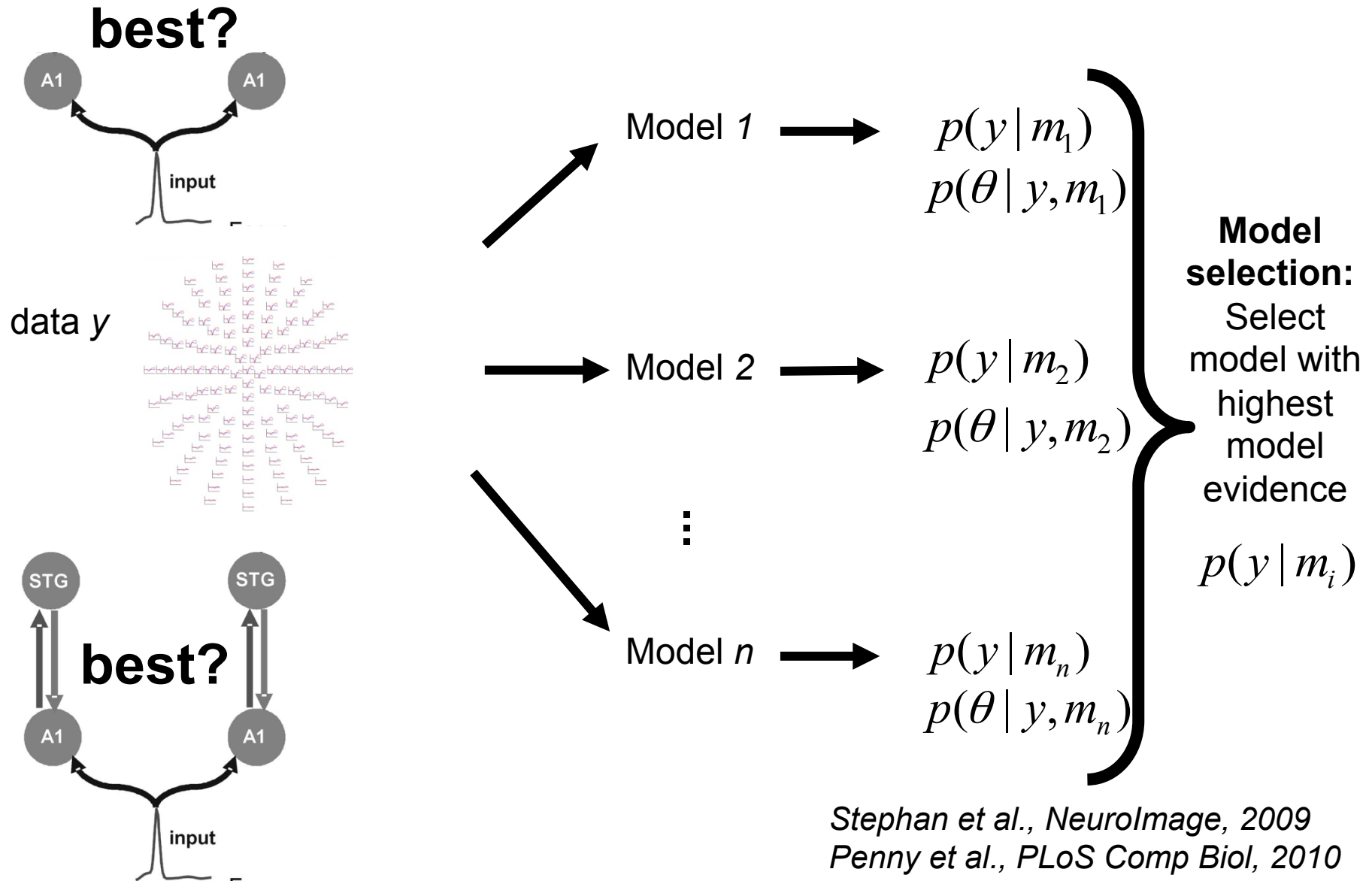


# Bayesian inference





# Model selection: Which model is the best?



# Overview

1 M/EEG analysis

2 Dynamic Causal Modelling – Motivation

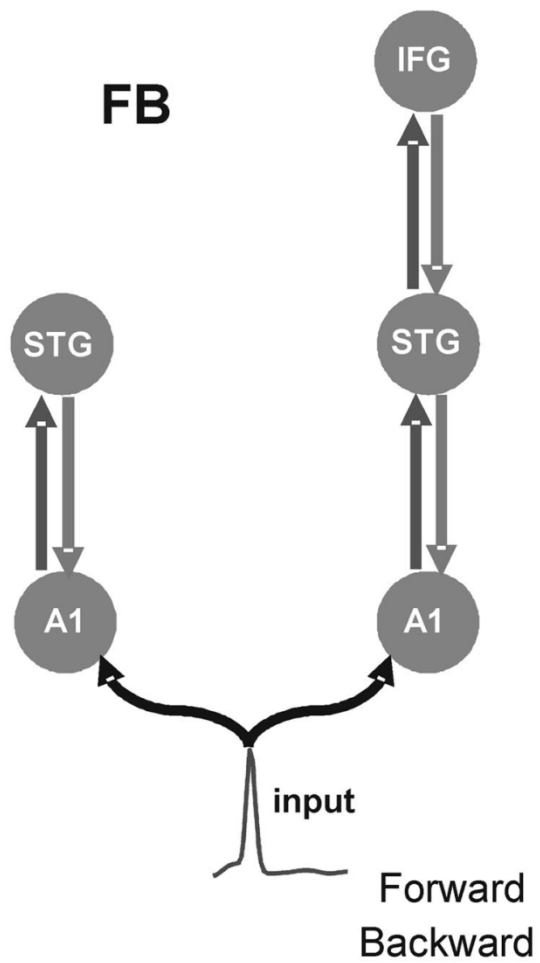
3 Dynamic Causal Modelling – Generative model

4 Bayesian inference

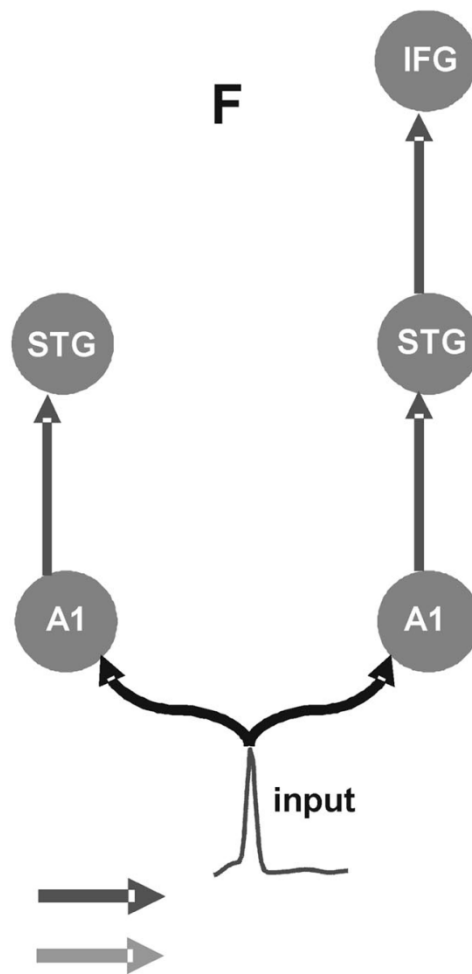
**5 Applications**

# Auditory evoked potential

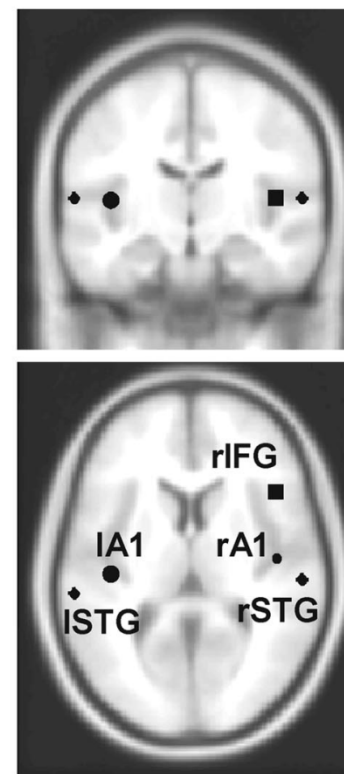
**A**  
with backward connections



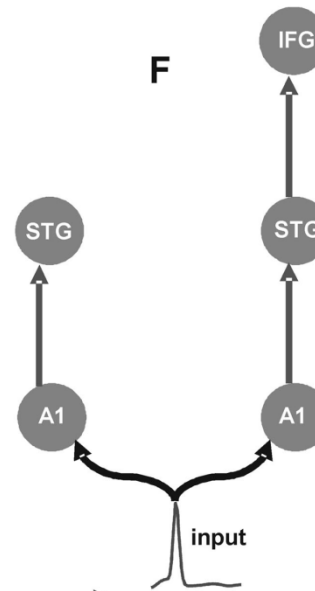
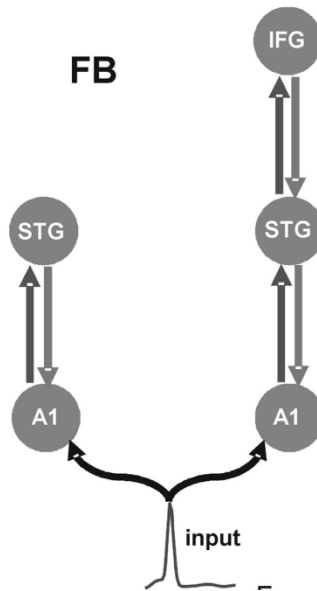
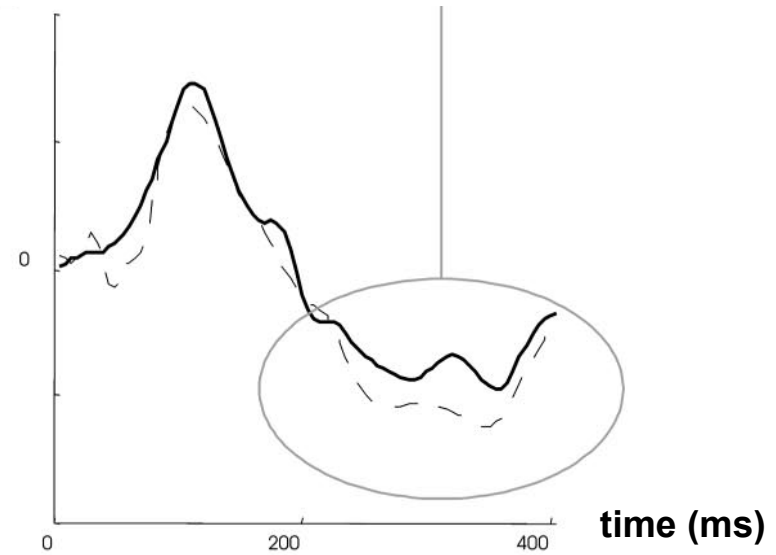
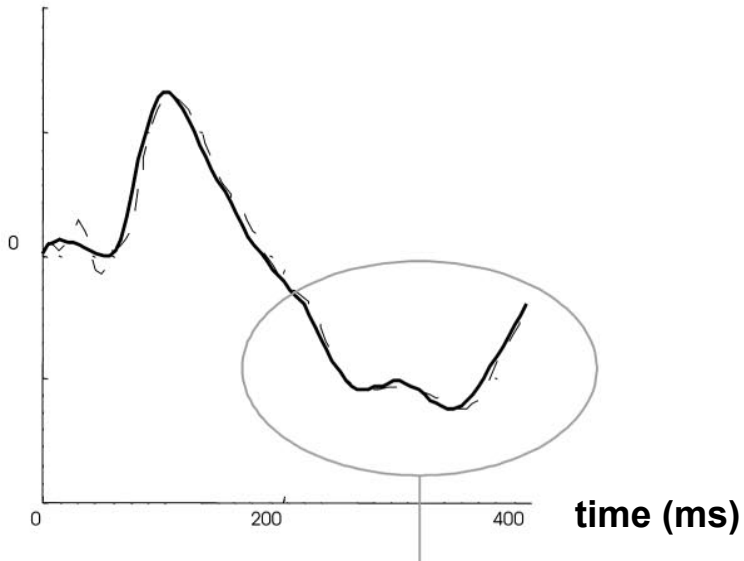
**B**  
and without



**C**



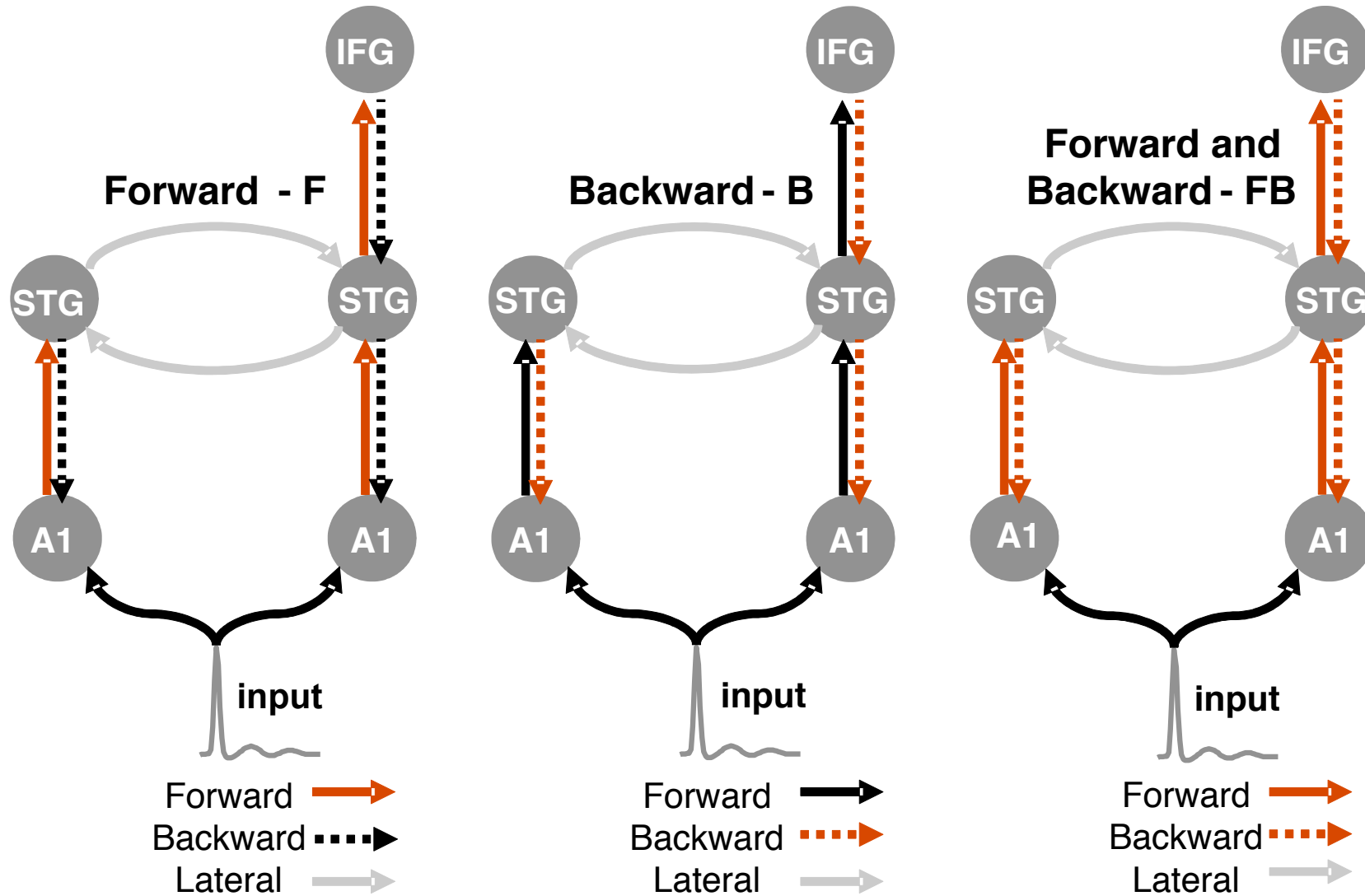
# Auditory evoked potential



*Garrido et al., PNAS, 2007*



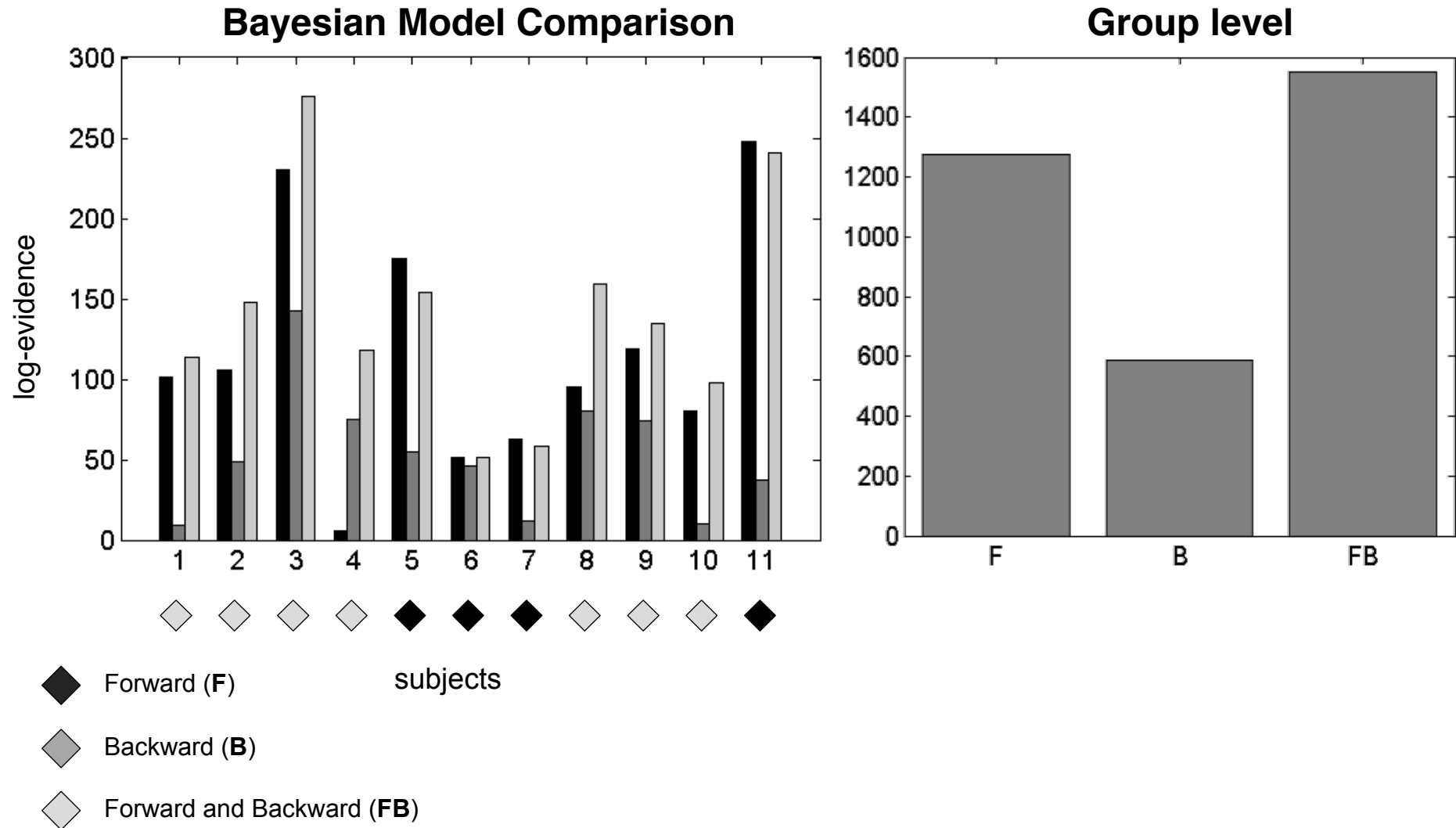
# Mismatch negativity: EEG



 modulation of effective connectivity

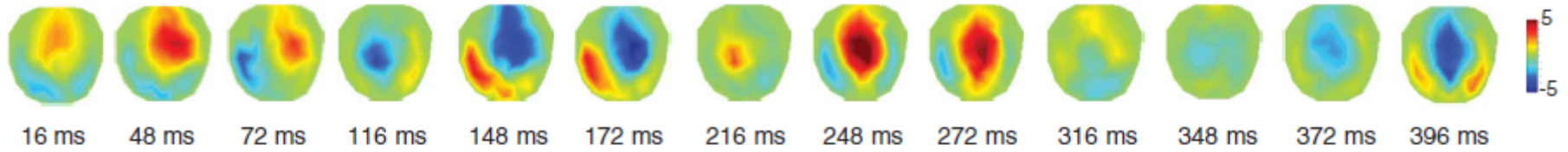
Garrido et al., NeuroImage, 2007

# MMN: Group model comparison

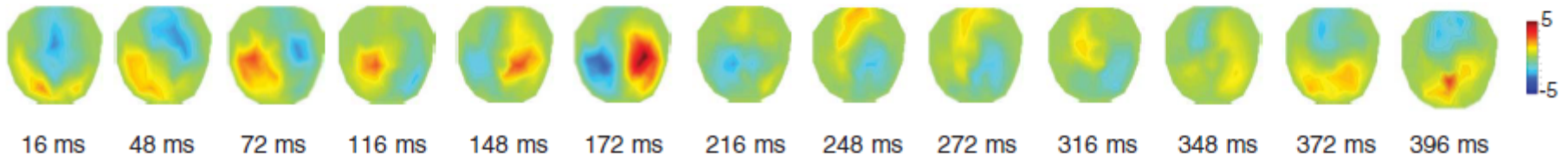


# Patient study: EEG, MMN

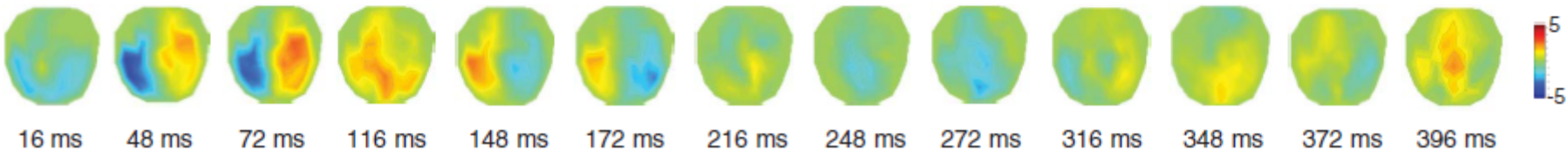
## Controls



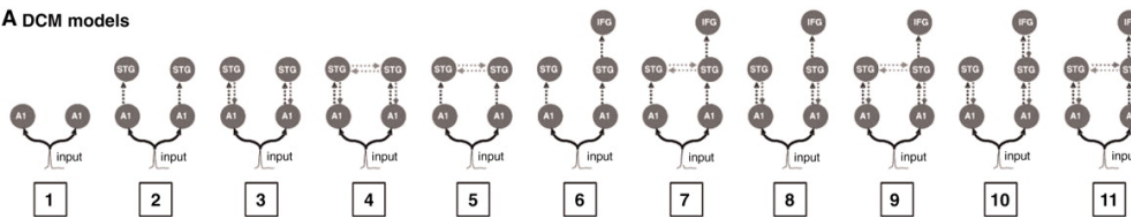
## MCS



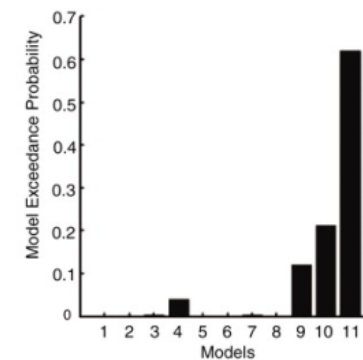
## VS



## A DCM models

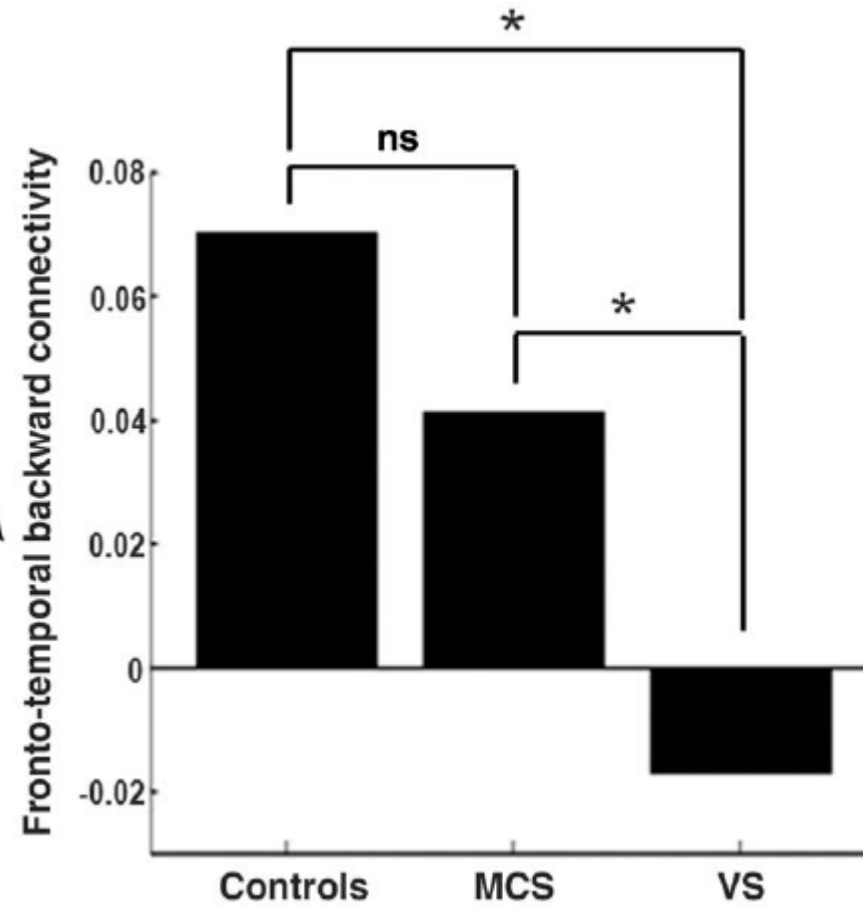
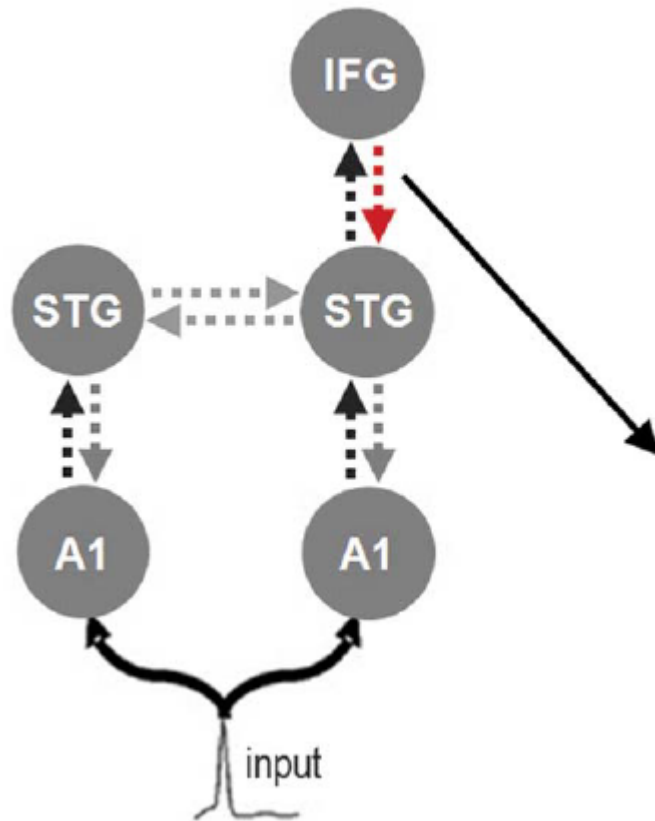


## D Population-level best model



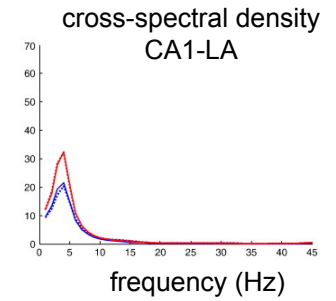
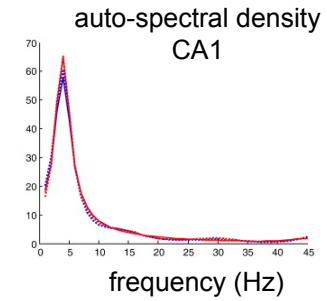
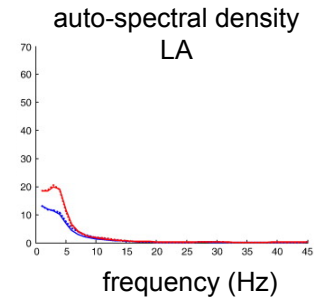
*Boly et al., Science, 2011*

# Patient study: EEG

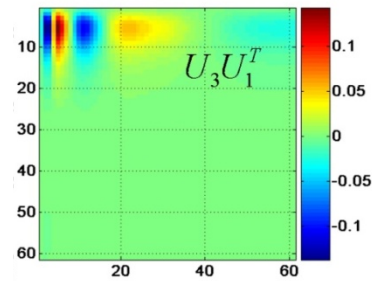


# DCM for EEG/MEG variants

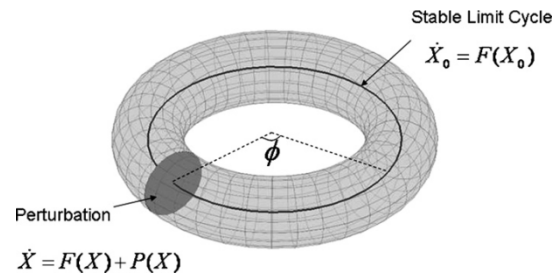
DCM for steady-state responses



DCM for induced responses



DCM for phase coupling

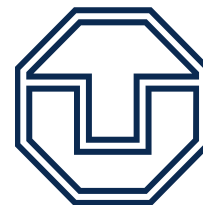


# Summary

- Dynamic Causal Modelling tests hypotheses about how brain sources communicate.
- Differences between conditions or groups are modelled as modulation of connectivity.
- Bayesian model comparison to identify best model among alternative, plausible models.

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Thank you!



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