Network Neuroscience 2025
June 2, 2025
Maastricht

# Brain Dynamics at the Limits of Consciousness and Thinking

Athena Demertzi, PhD

Director, Physiology of Cognition Lab
GIGA Institute
CRC-Human Imaging Unit
University of Liège
BELGIUM

LIÈGE université
GIGA
CRC Human Imaging

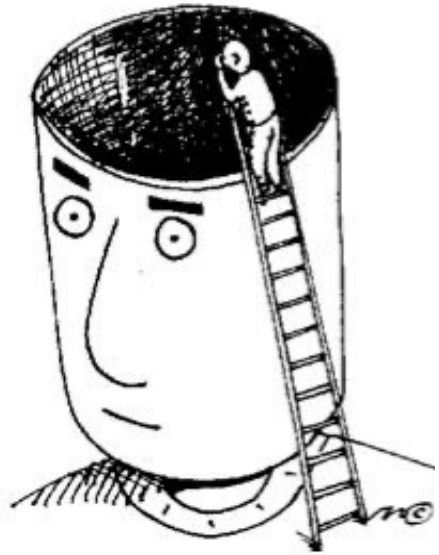
# States of (Un)consciousness

Clinical

Disorders of Consciousness
Anaesthesia

Physiological

Sleep

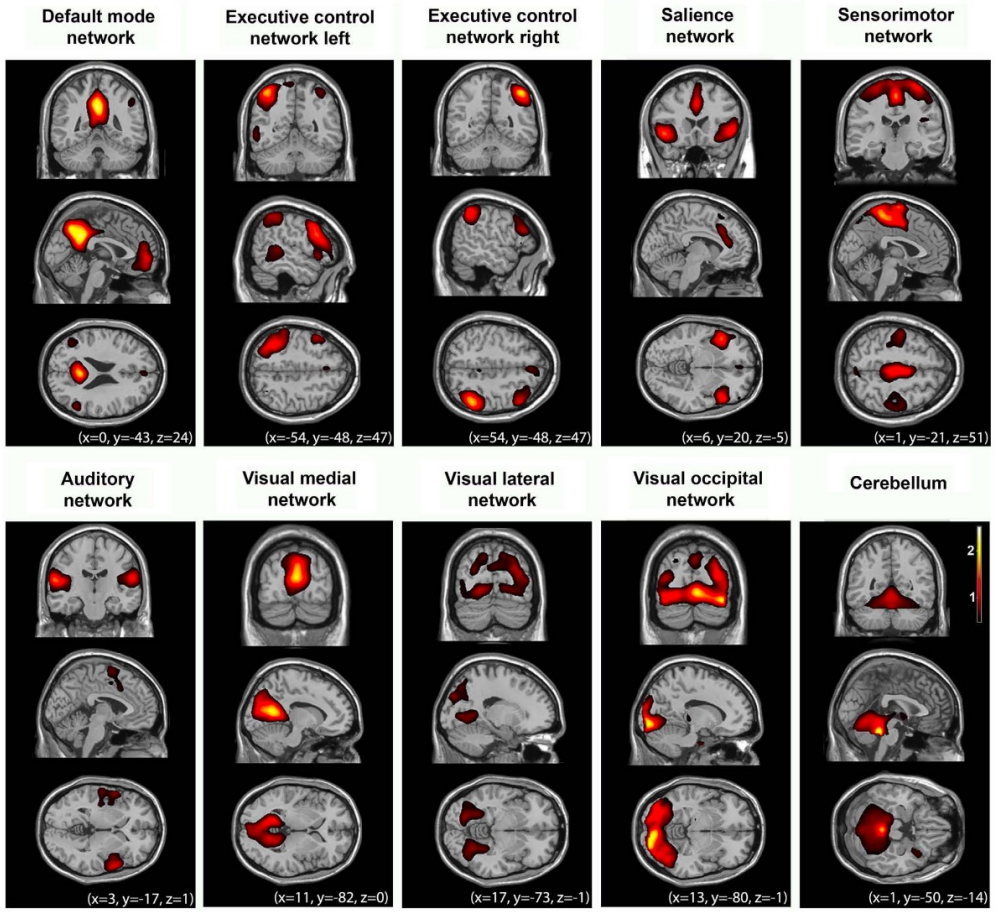


Wakefulness

Mind Blanking

# Spontaneous mind

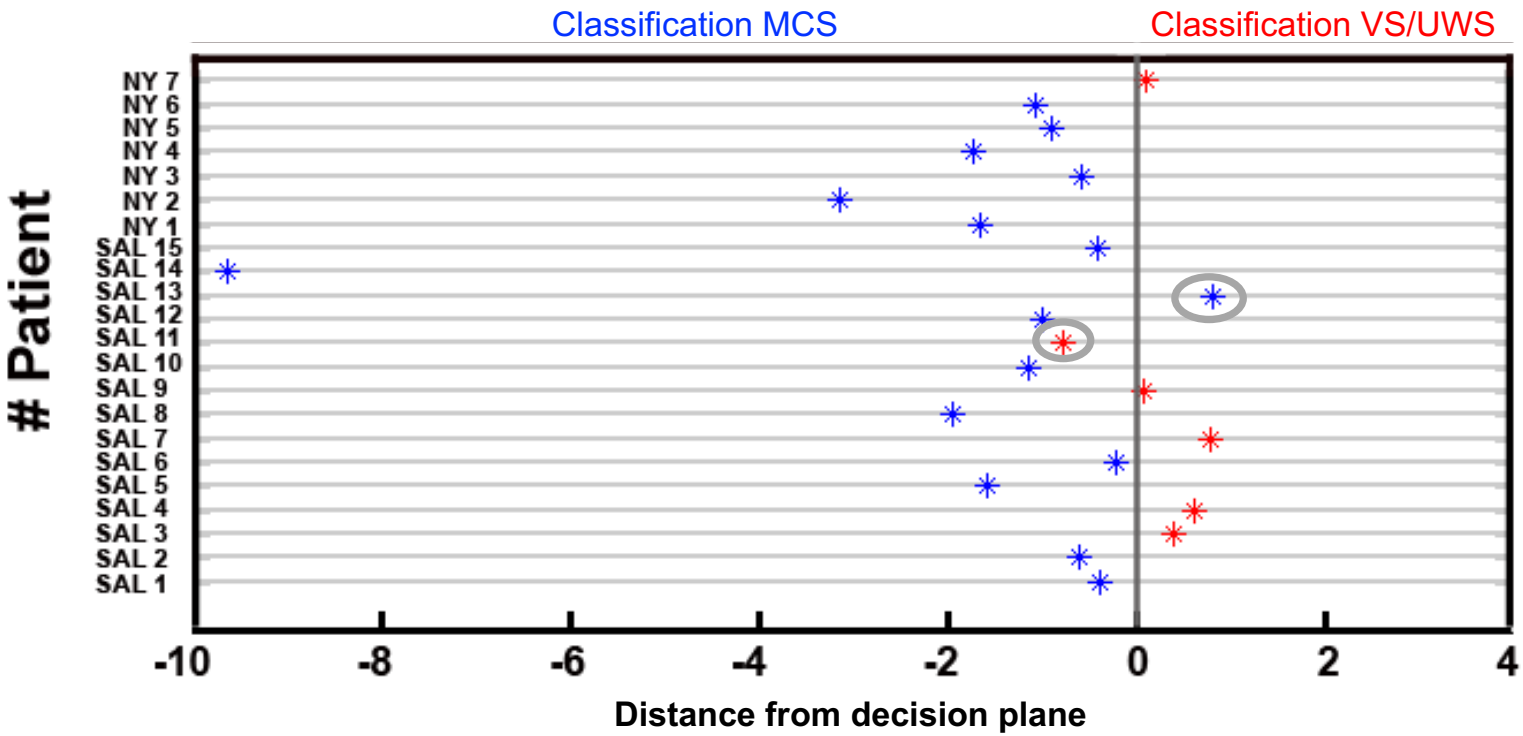

# Spontaneous brain

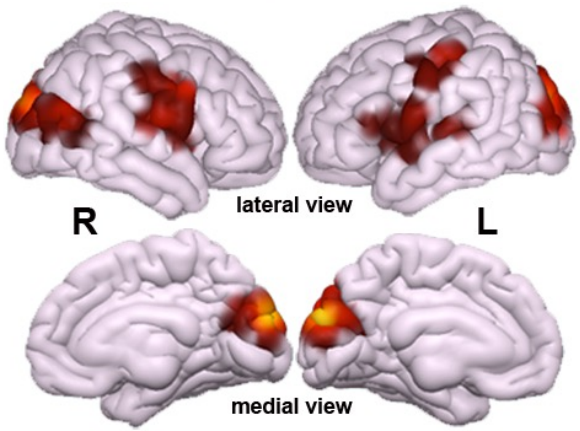



Heine, Soddu, …. Demertzi. ***Frontiers Psychol*** 2012

# DOC separation based on cross-modal interactions

- Training set: 45 DOC (26 MCS, 19 VS/UWS)
  - 14 trauma, 28 non-trauma, 3 mixed
  - 34 patients assessed >1m post-insult
- Test set:
  - **16 MCS**, **6 VS/UWS** (15 non-trauma; all chronic)
  - 2 different centers

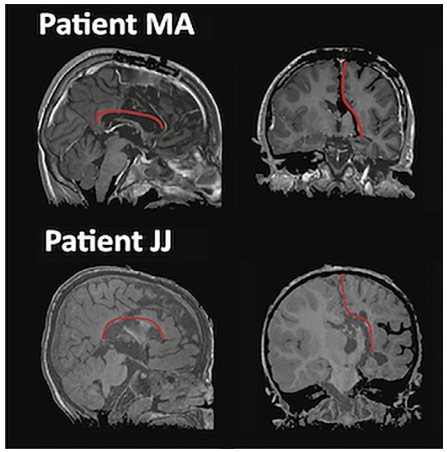


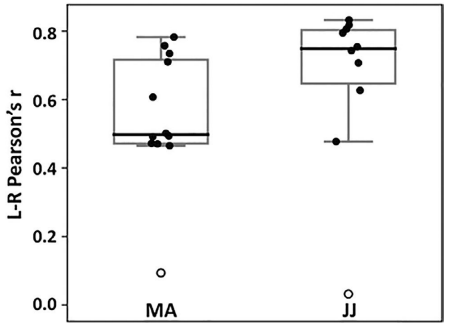

Demertzi & Antonopoulos et al, ***Brain*** 2015

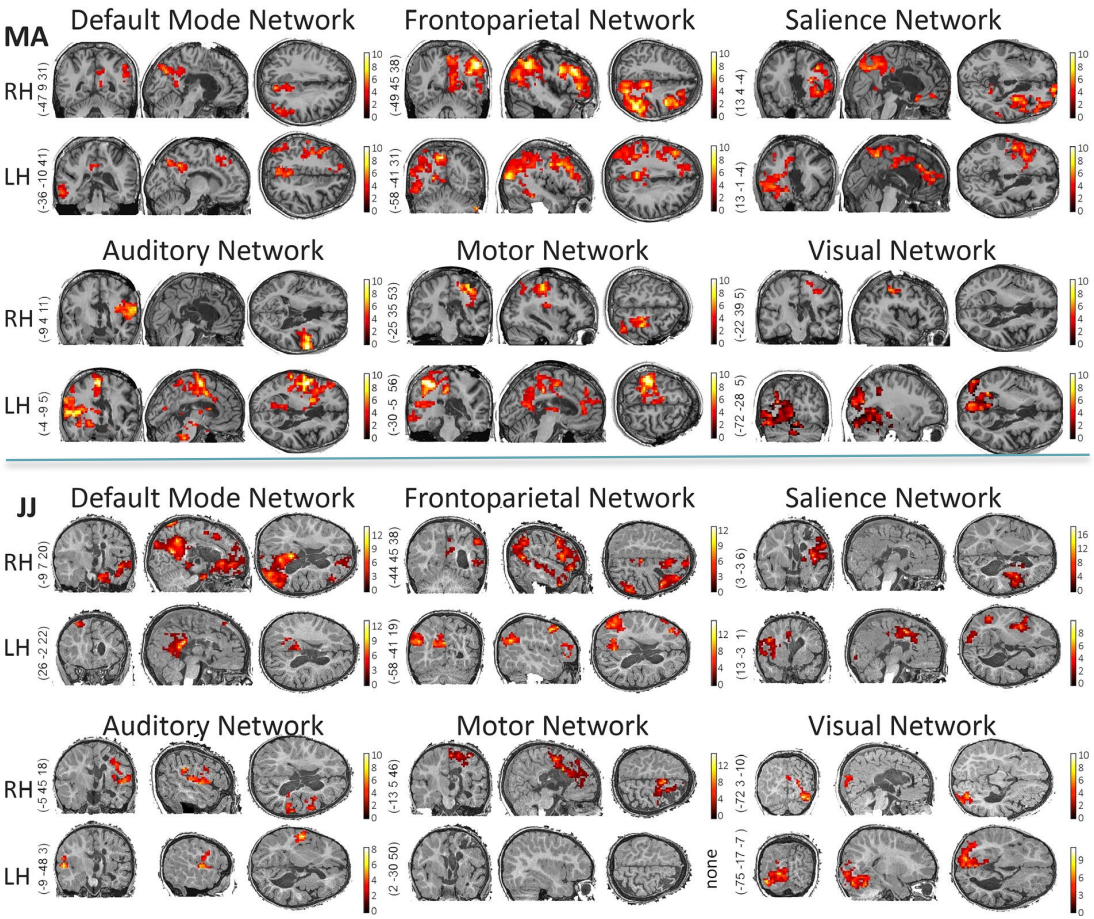
# Lower cross-modal interaction in the isolated brain

Complete hemispherotomy




Inter-hemispheric connectivity



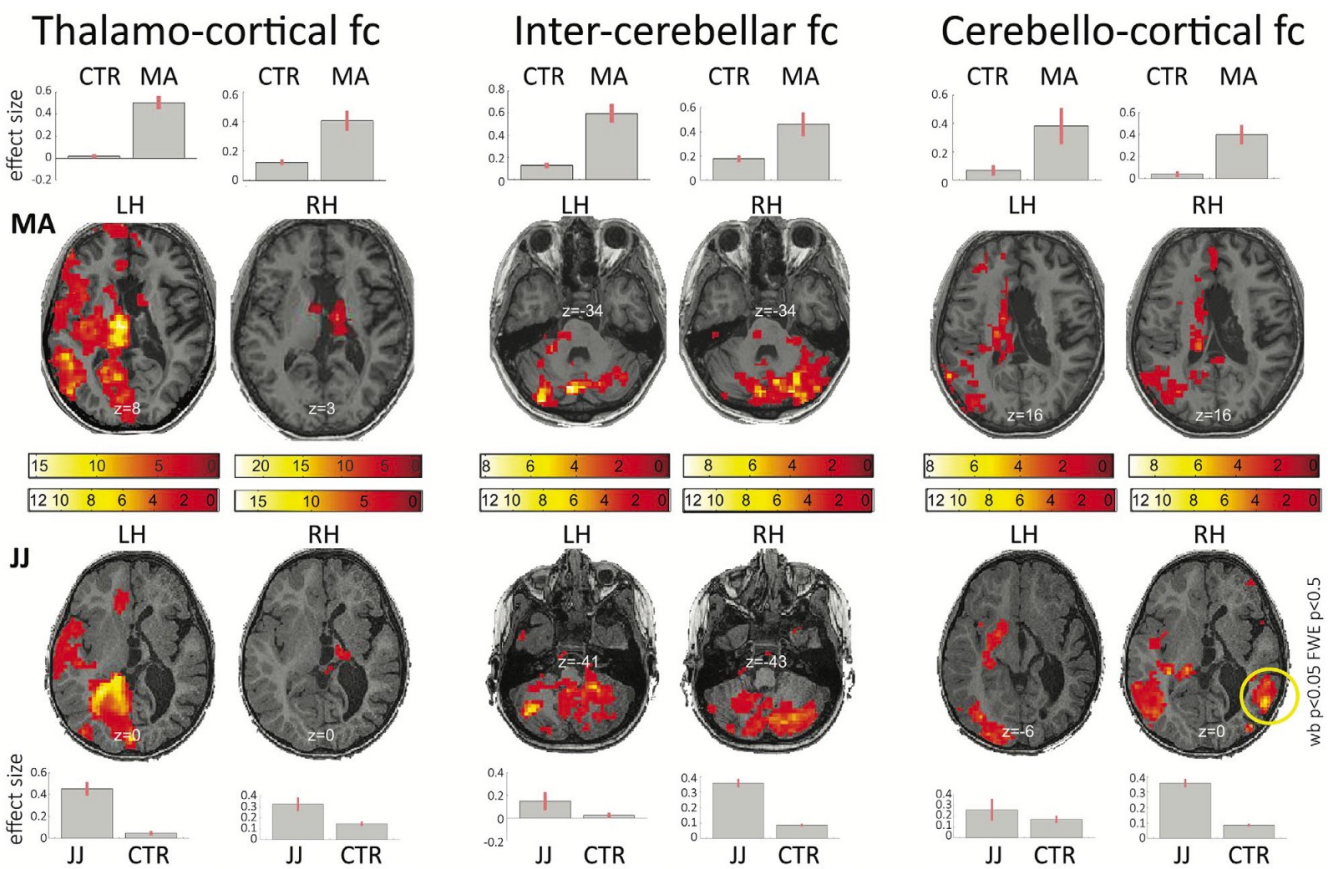



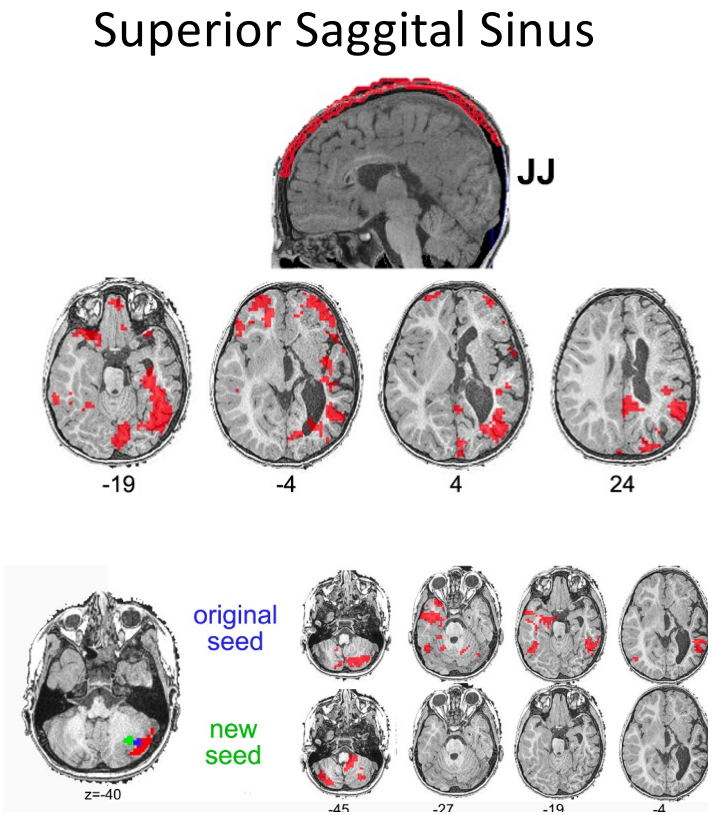

Blauwblomme* & Demertzi*, Tacchela, Fillon, Bourgeois, Losito, Eisermann, Marinazzo, Raimondo, Alcauter, Van De Steen, Colenbier, Laureys, Dangouloff Ros, Naccache, Boddaert, Nabbout et al, ***Epilepsia Open*** 2020

ASSISTANCE PUBLIQUE HÔPITAUX DE PARIS

Necker ENFANTS MALADES HÔPITAL UNIVERSITAIRE

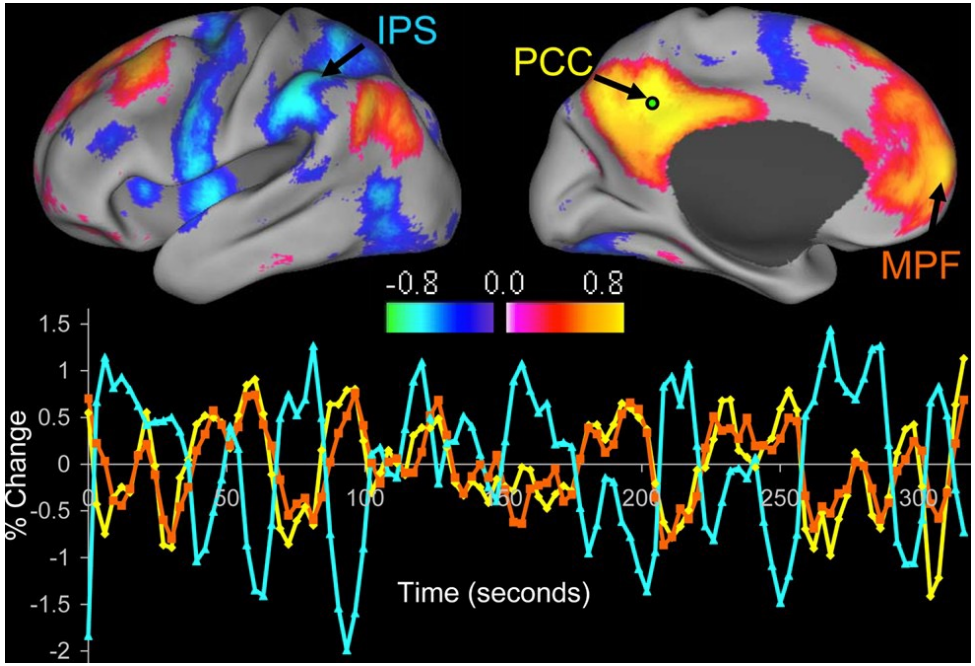
# Mediation of subcortical regions in functional reorganization



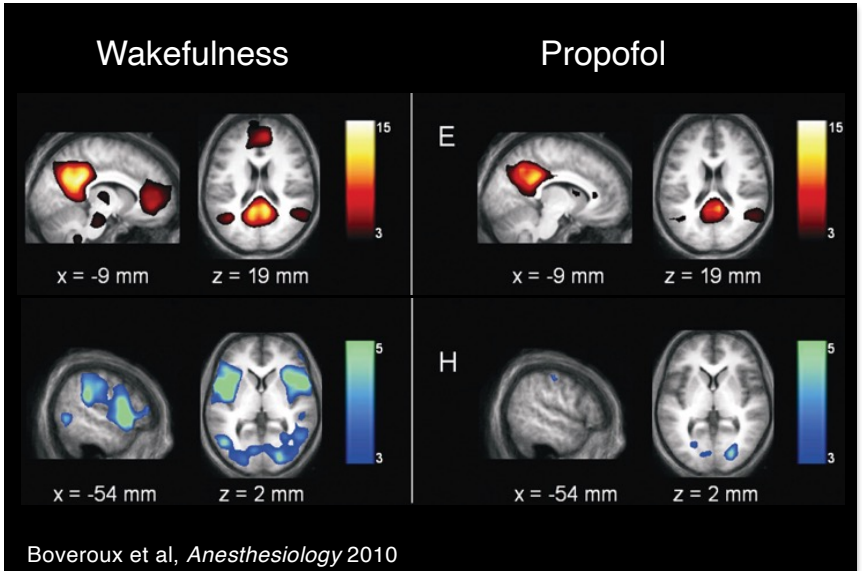

Blauwblomme* & Demertzi*, Tacchela, Fillon, Bourgeois, Losito, Eisermann, Marinazzo, Raimondo, Alcauter, Van De Steen, Colenbier, Laureys, Dangouloff Ros, Naccache, Boddaert, Nabbout et al, ***Epilepsia Open*** 2020

# Functional anticorrelations



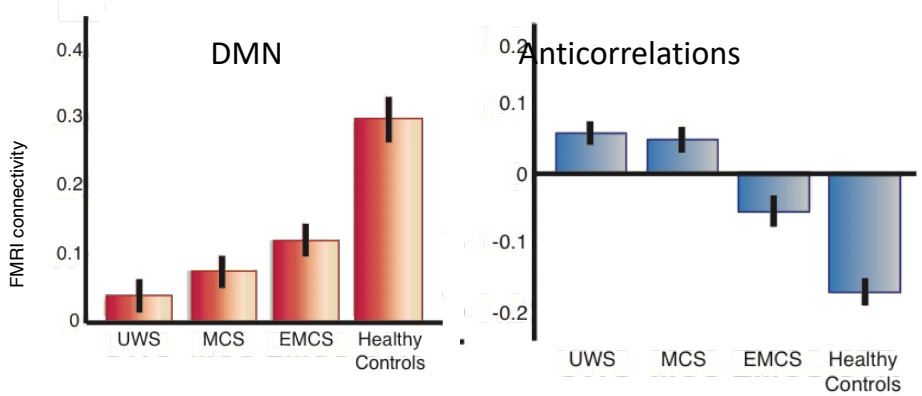

Fox et al, ***PNAS*** 2005
Demertzi & Whitfield-Gabrieli: **Neurology of Consciousness** 2nd ed. 2015

## Propofol Anesthesia



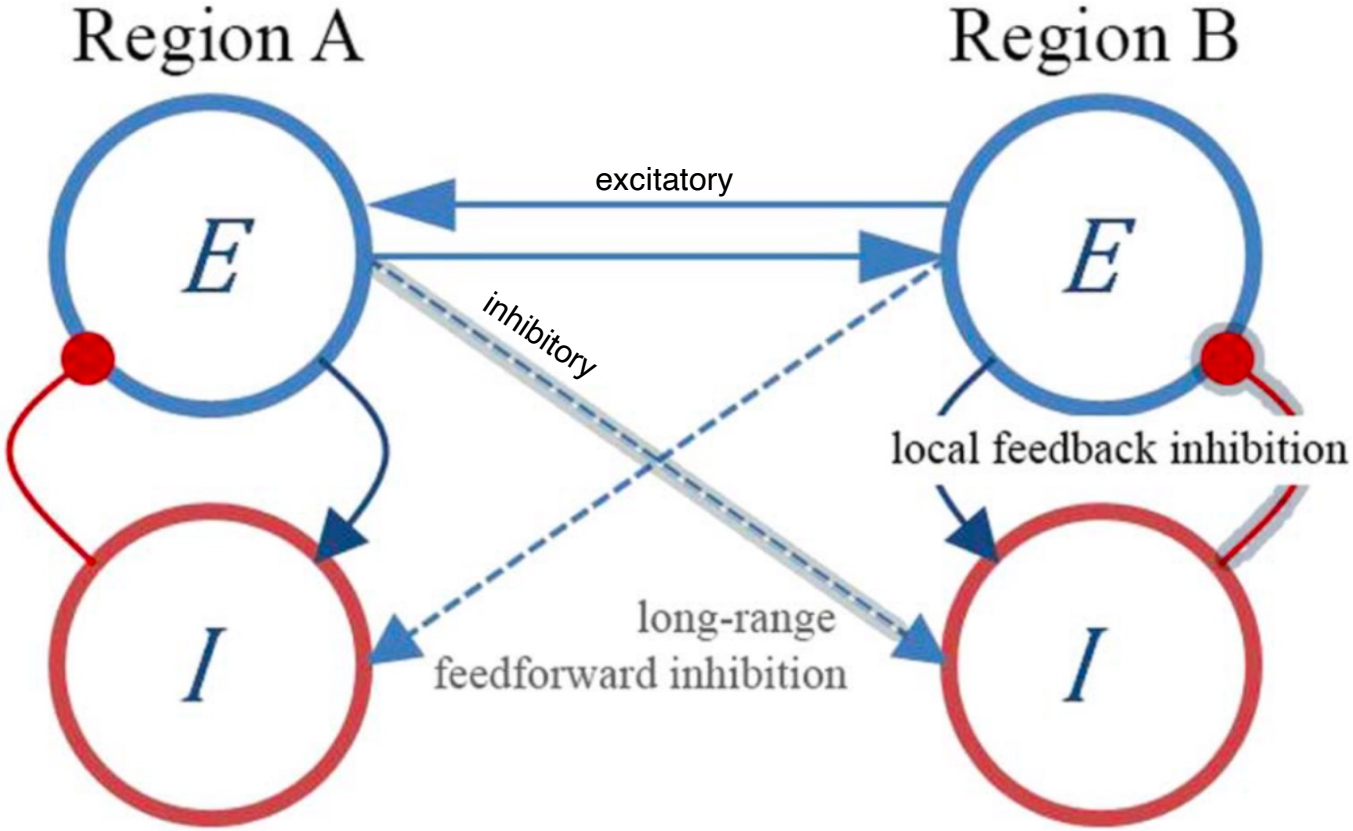

Boveroux et al, *Anesthesiology* 2010

## Disorders of Consciousness




Di Perri, …, Demertzi*, Laureys*, Soddu*, *Lancet Neurol* 2016

# Anticorrelations as a result of neural inhibition




Ignition

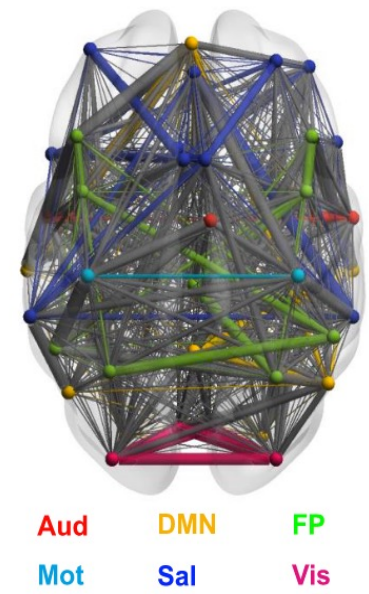
Deco et al., *Sci Adv* 2021
Joglekar et al, *Neuron* 2018

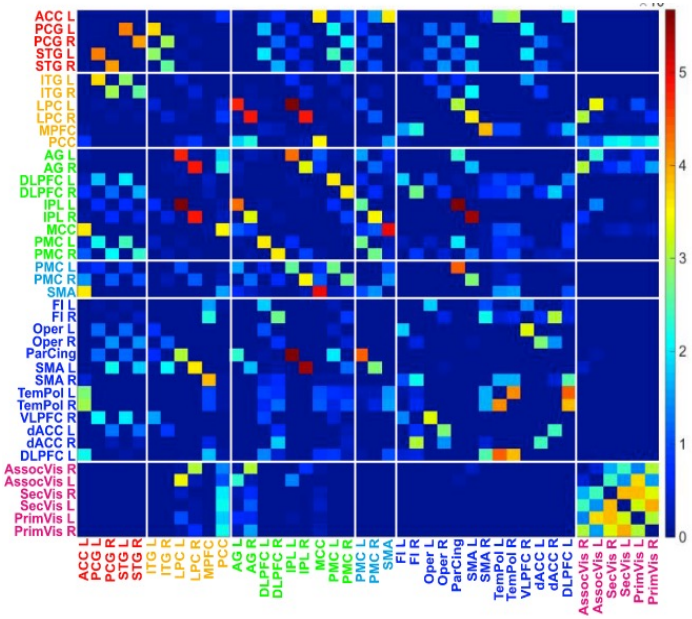
Demertzi, Kucyi, Ponce-Alvarez, Keliris, Whitfield-Gabrieli, Deco. ***Network Neurosci*** 2022

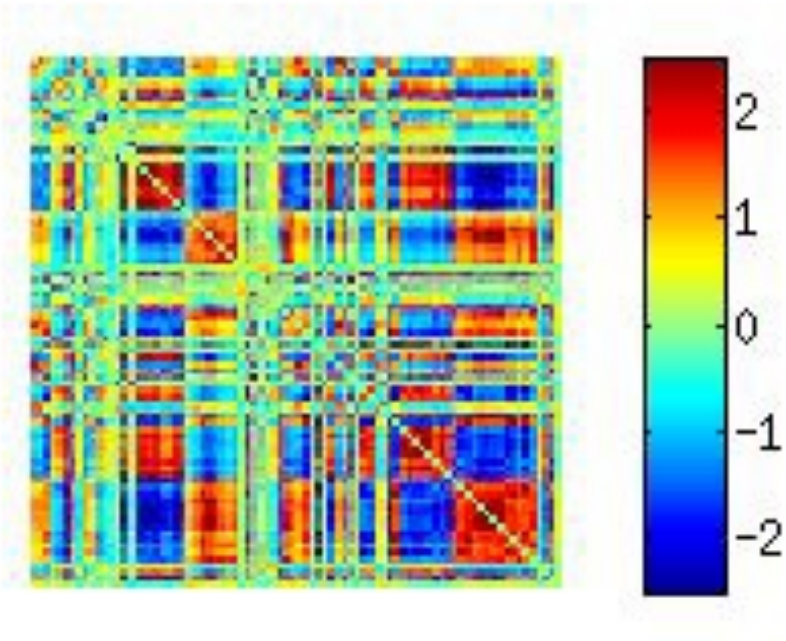
# The brain as a network

100 billion neurons, ~100 trillion synaptic connections

## The Connectome

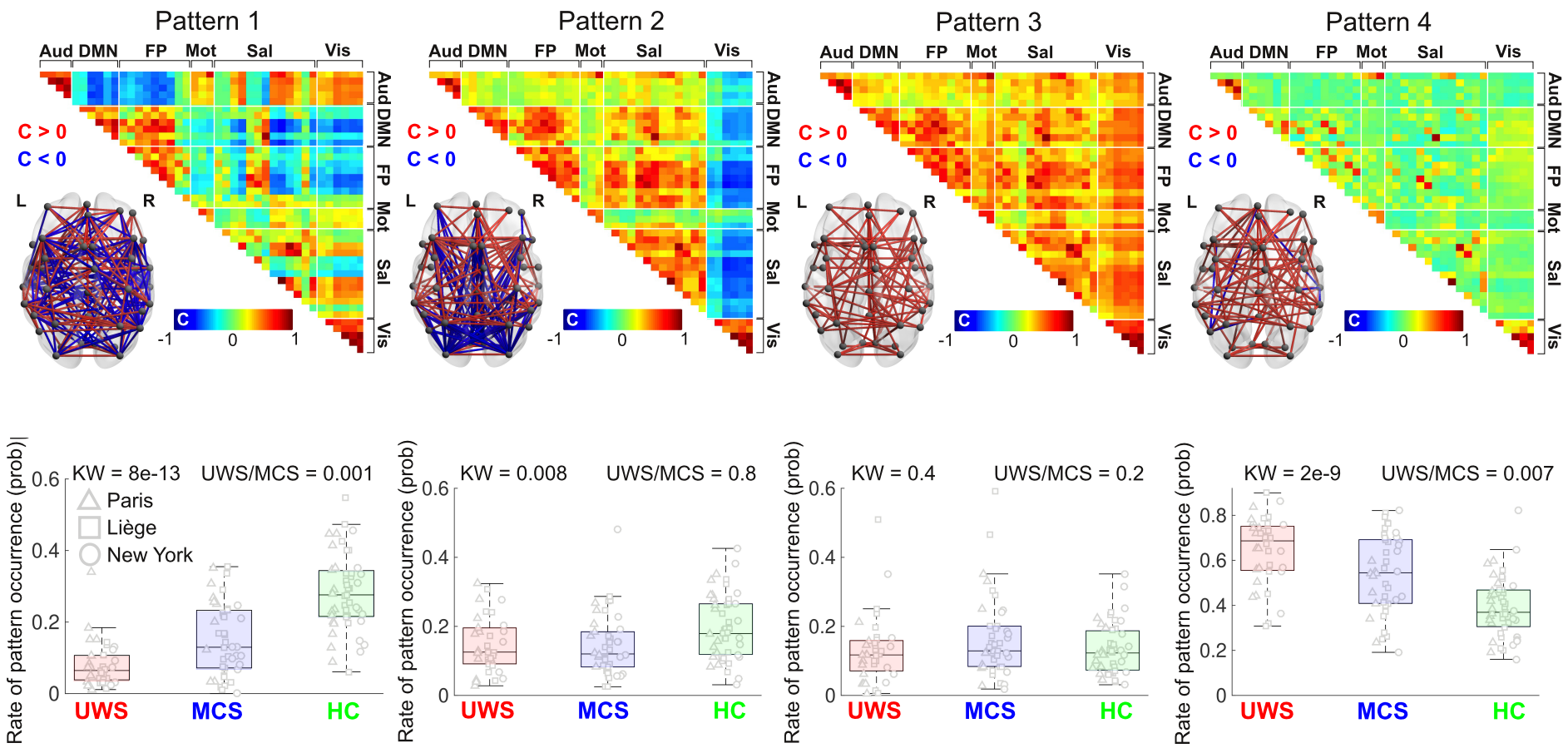


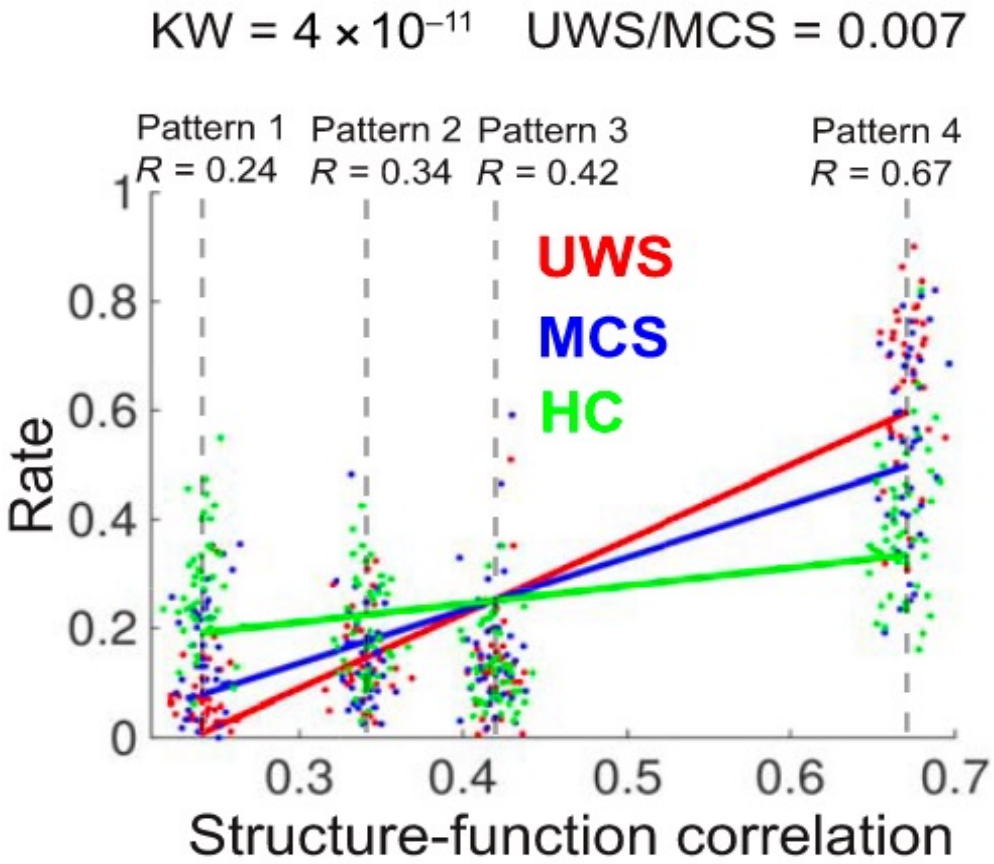

Fornito, Zalesky, Bullmore. Ch 1: An Introduction to Brain Networks. *Fundamentals of Brain Network Analysis, Academic Press* 2016
Sporns, Tononi, & Koetter. ***PLoS Comput Biol*** 2005

# “Rich” connectivity in communicating states



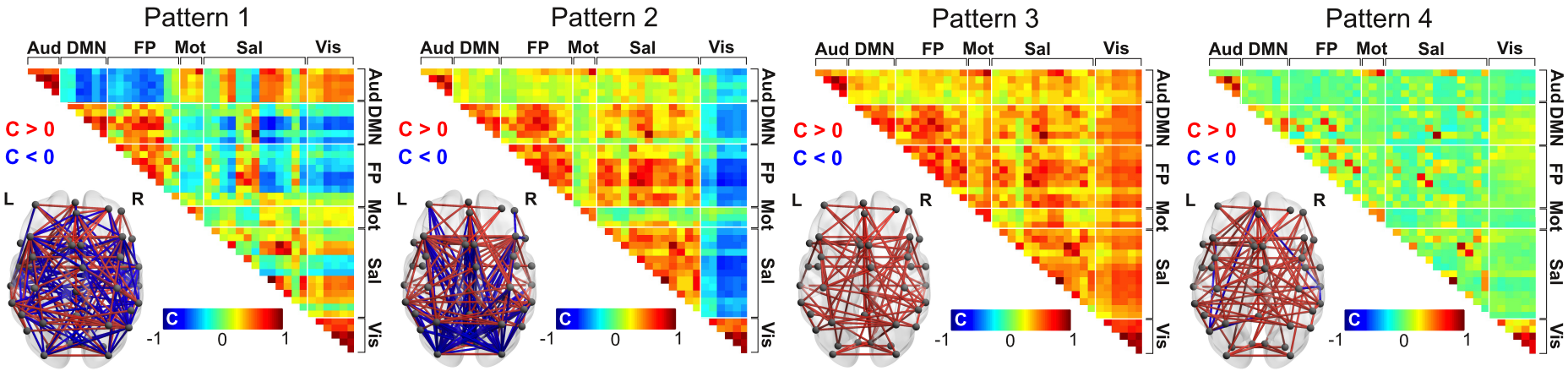

Demertzi* & Tagliazucchi*, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt.
***Science Advances*** 2019

# “Rich” connectivity in communicating states

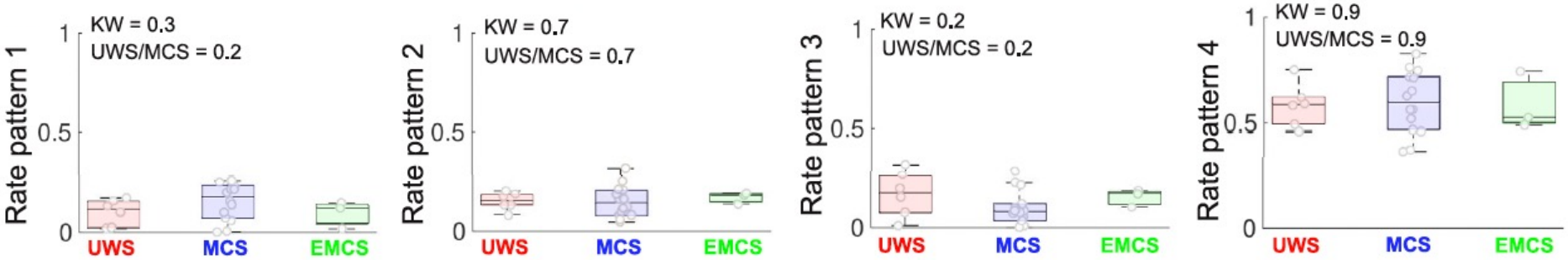



Demertzi* & Tagliazucchi*, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt.
***Science Advances*** 2019

# Simple connectivity in Unconsciousness

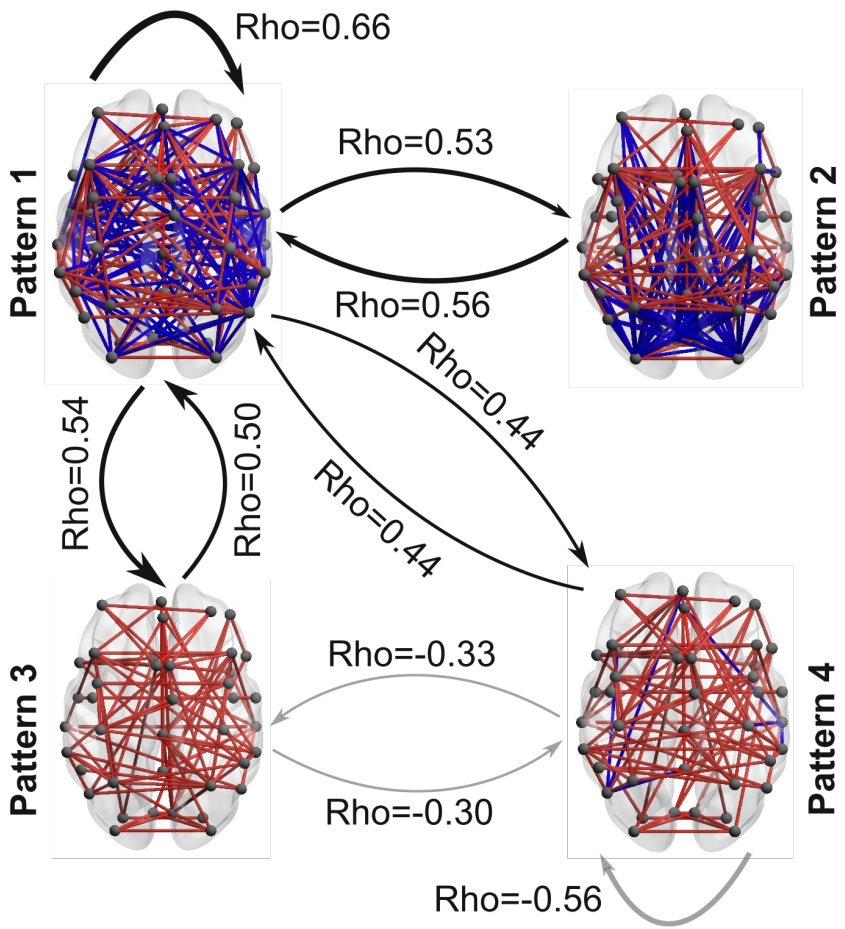



Propofol anesthesia




Demertzi* & Tagliazucchi*, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt. ***Science Advances*** 2019

# Higher dynamism in conscious states

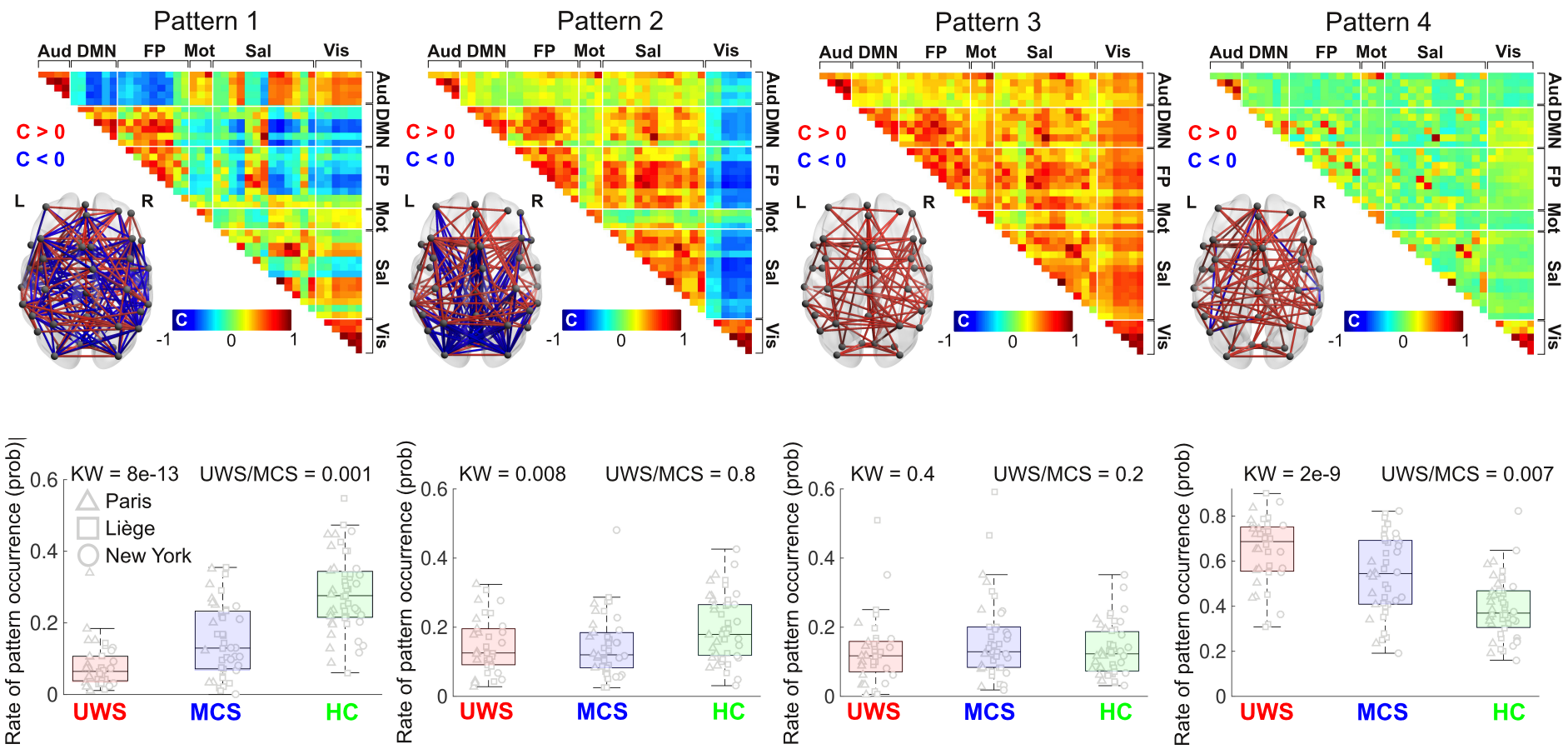



Healthy > MCS > UWS

UWS > MCS > Healthy

Demertzi* & Tagliazucchi*, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt.
***Science Advances*** 2019

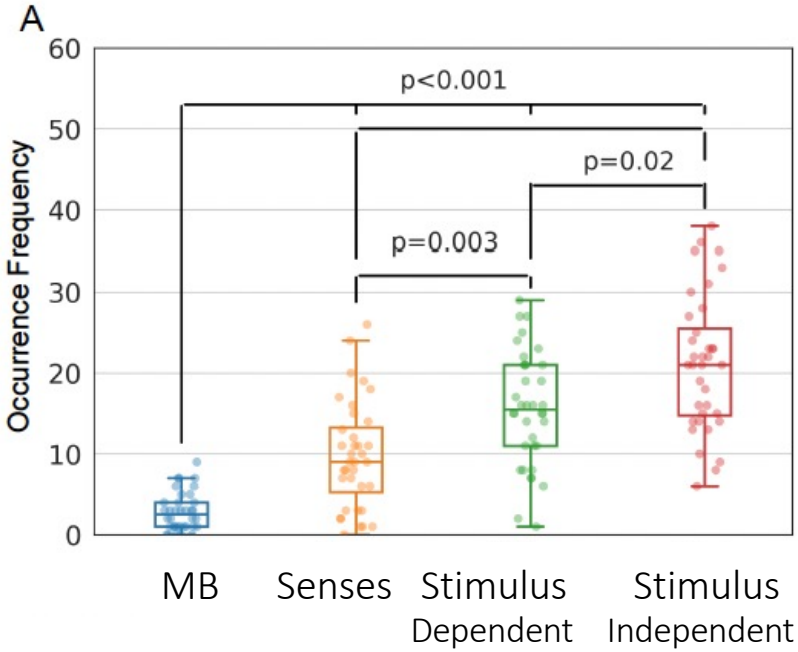
# What do these patterns mean?



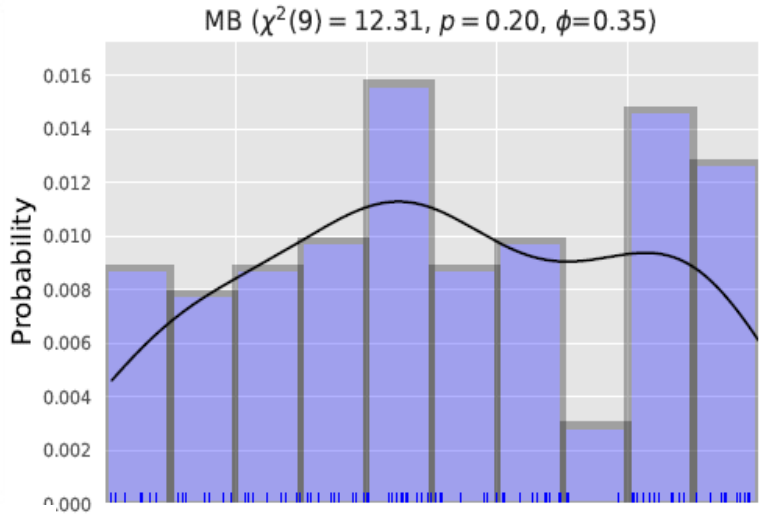

Demertzi* & Tagliazucchi*, Dehaene, Deco, Barttfeld, Raimondo, Martial, Fernández-Espejo, Rohaut, Voss, Schiff, Owen, Laureys, Naccache, Sitt. ***Science Advances*** 2019

# Mind Blanking

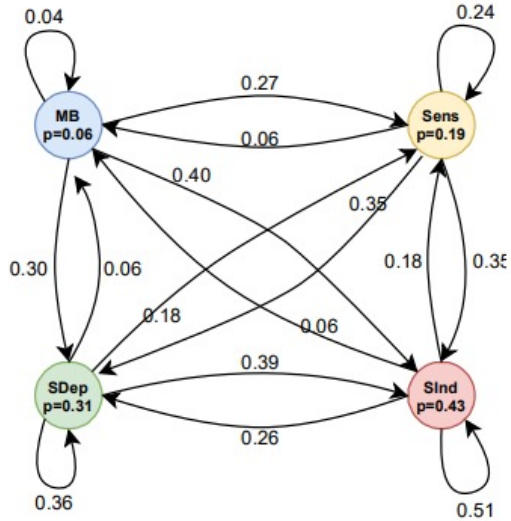
## Less frequent




## Equally probable across time



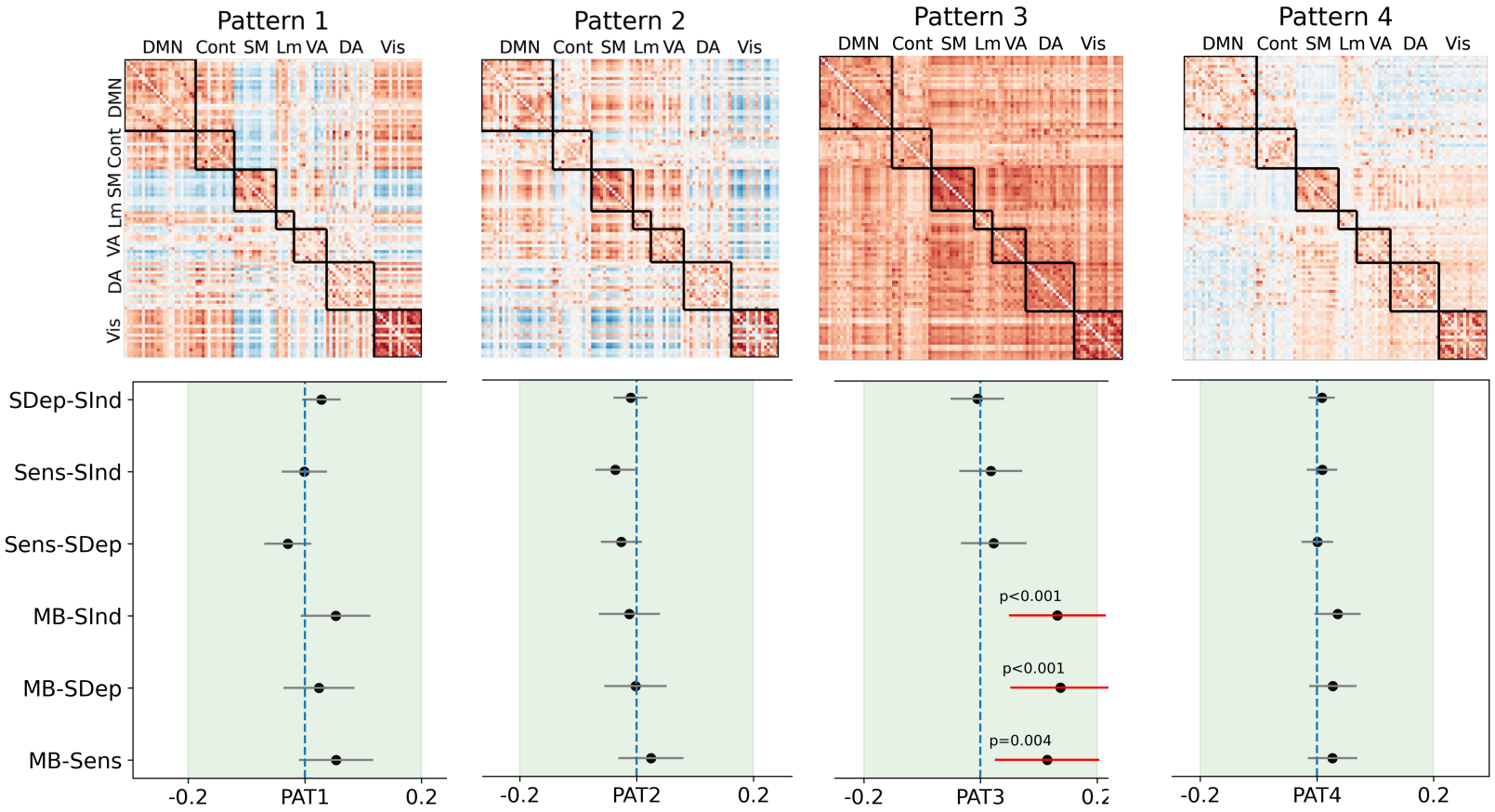

## Transient relay




n subjects= 36
n probes = 50
duration = 48-58min

Mortaheb, Van Calster, Raimondo, Klados, Boulakis, Georgoulaa, Majerus, Van De Ville*, Demertzi*. ***PNAS*** 2022
Van Calster, D'Argembeau, Salmon, Peters, Majerus, ***J Cogn Neurosci*** 2017

# MB is linked to a hyper-connected pattern

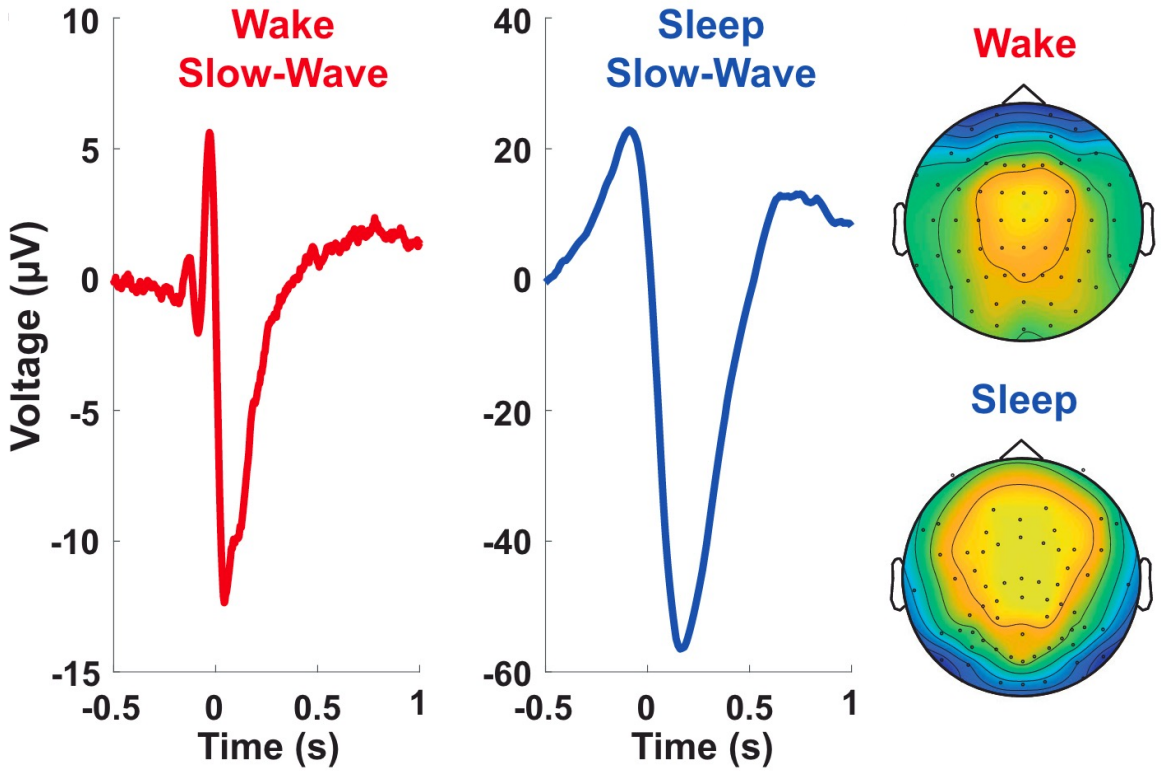


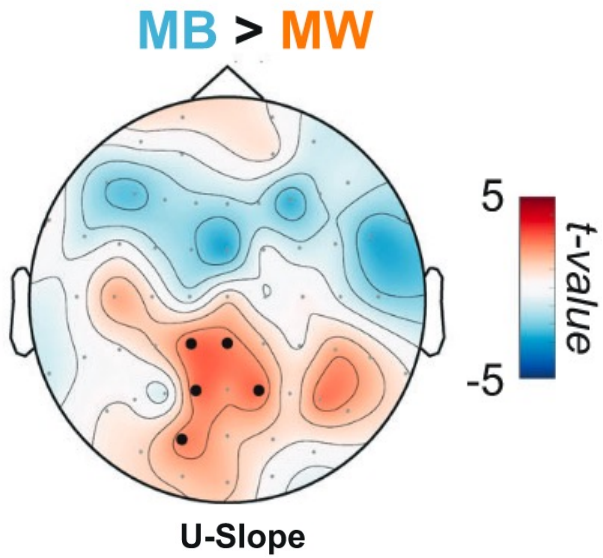

Mortaheb, Van Calster, Raimondo, Klados, Boulakis, Georgoulaa, Majerus, Van De Ville*, Demertzi*. ***PNAS*** 2022

# Slow wave-like activity in wakefulness

Properties of slow waves

Predictive of mental states

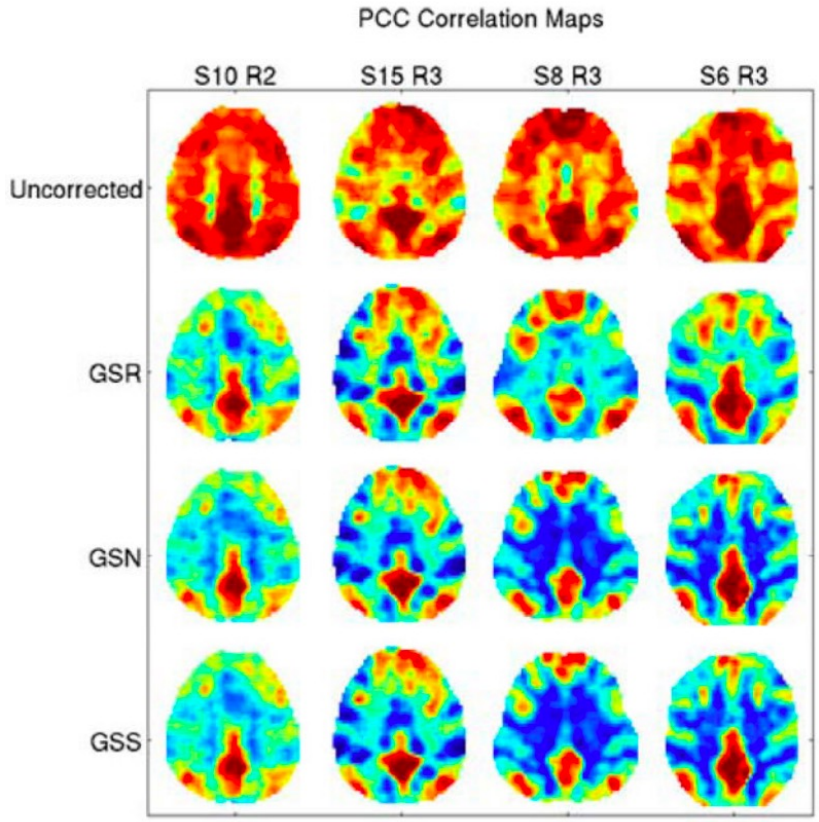



Andrillon et al, ***Nat Communications*** 2021

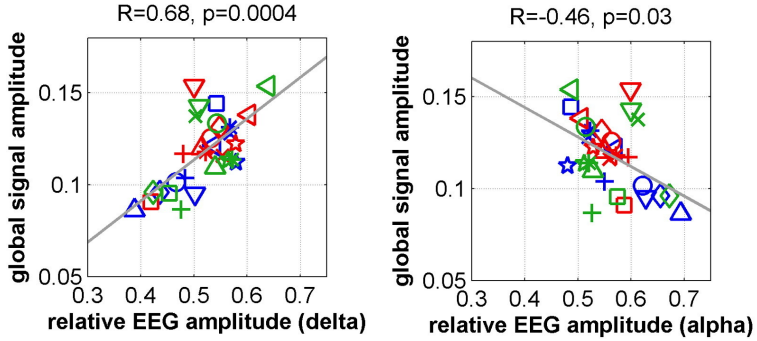
# Higher Global Signal amplitude → Lower vigilance

## The Global Signal

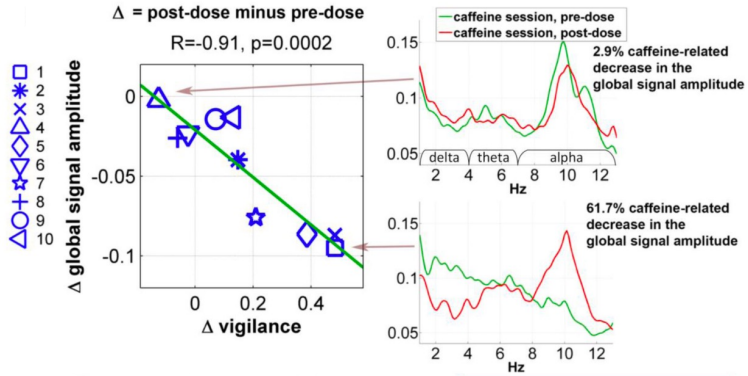



Liu et al, ***NeuroImage*** 2017

## GS amplitude is linked to low arousal

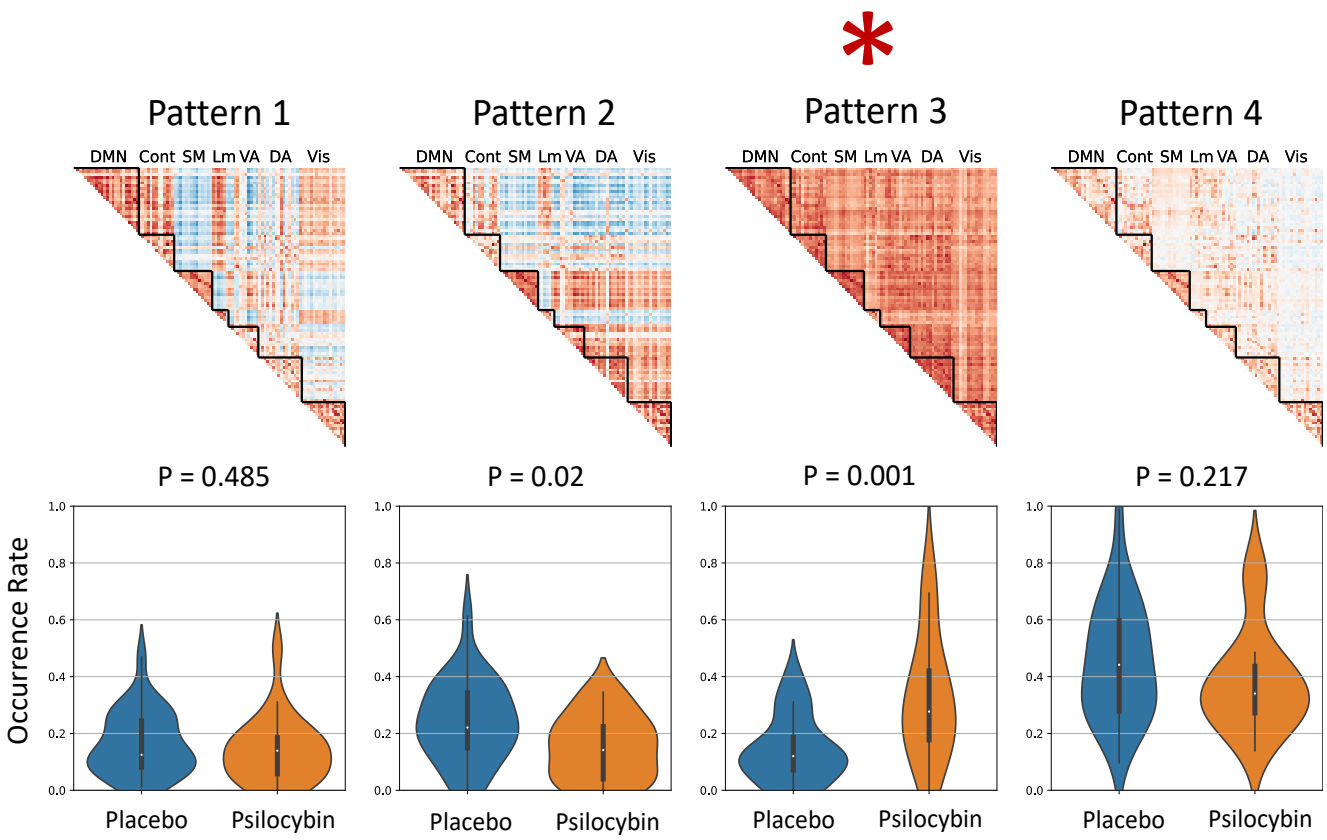


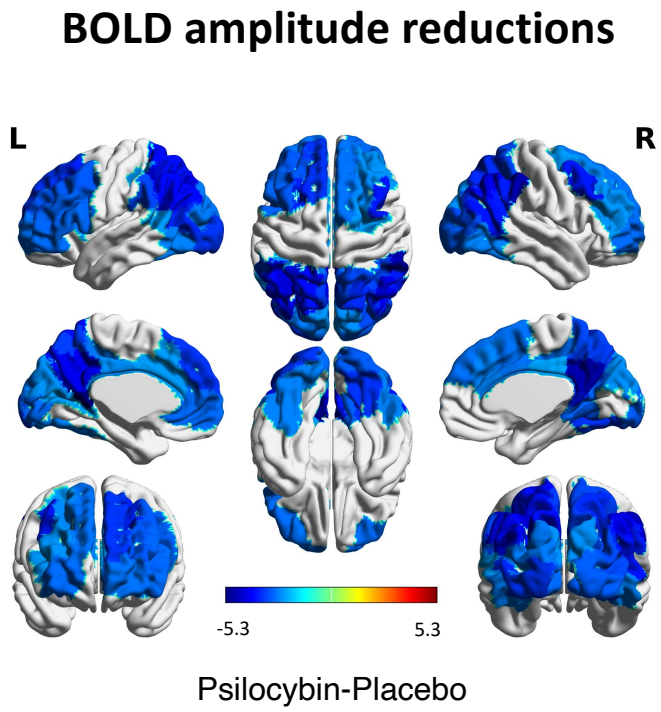

## GS amplitude decreases with caffeine intake




Wong et al, ***Neuroimage*** 2013

# Lower Global Signal amplitude → Higher vigilance



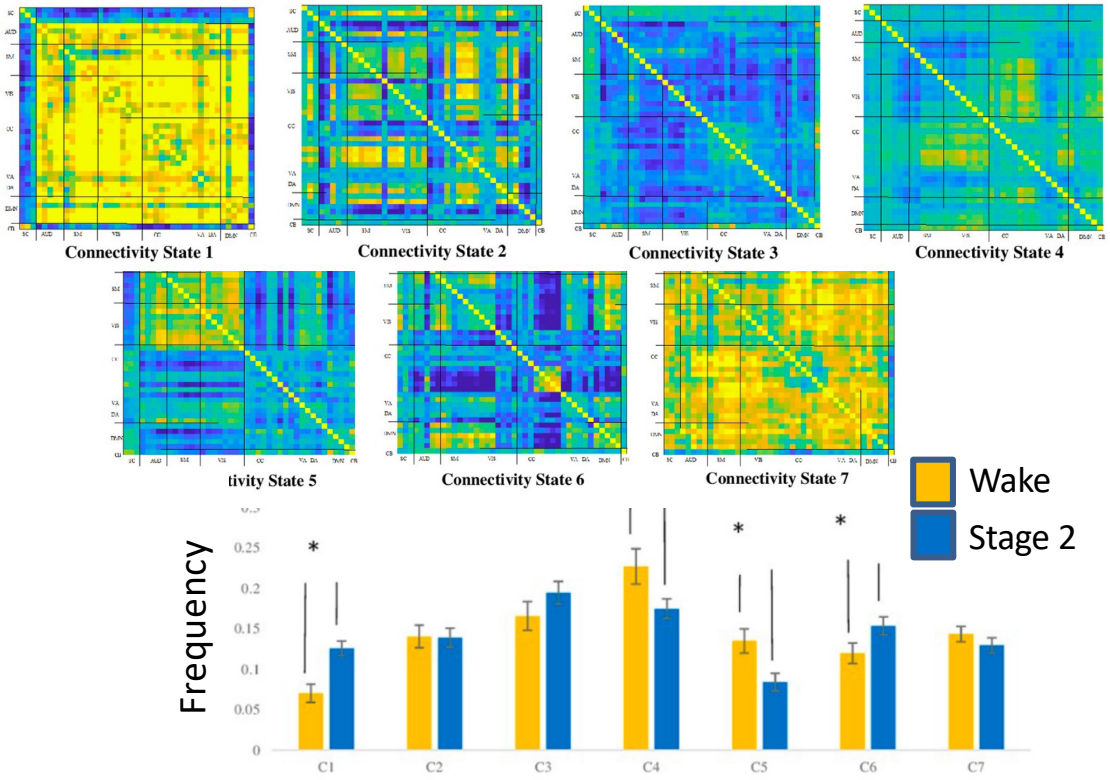




Mortaheb, Fort, Mason, Mallaroni, Ramaekers, Demertzi. ***Biol Psychiatry-CNNI*** 2024

# Higher connectivity in unconscious states

**NREM sleep**

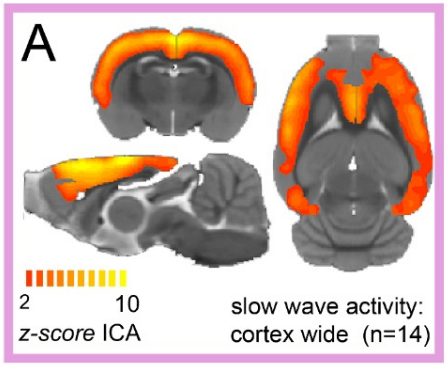
Humans

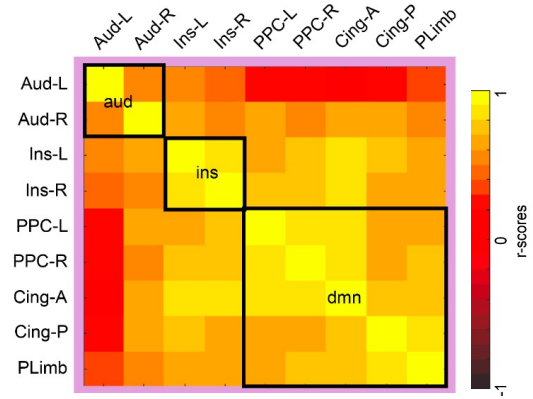



El-Baba et al, ***PLOS One*** 2019

**Isoflurane anesthesia**

Rats

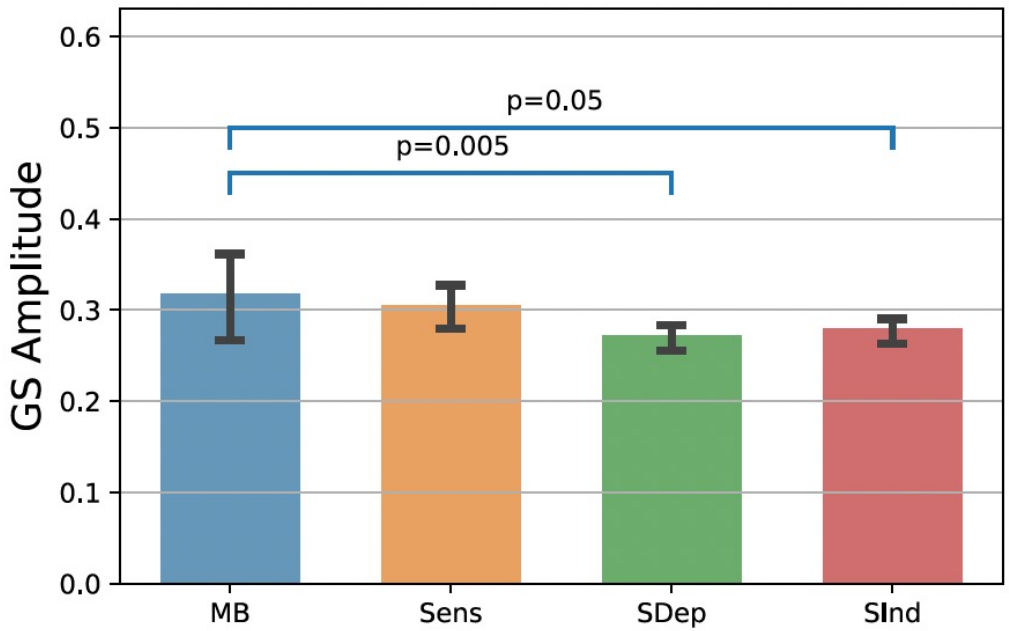


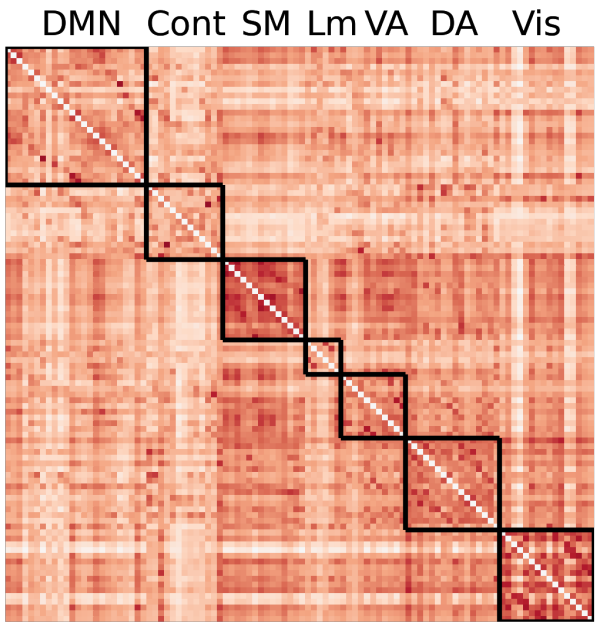

Aedo-Jury et al, ***eLife*** 2019

# MB is mediated by low arousal levels

**Higher Global Signal Amplitude**

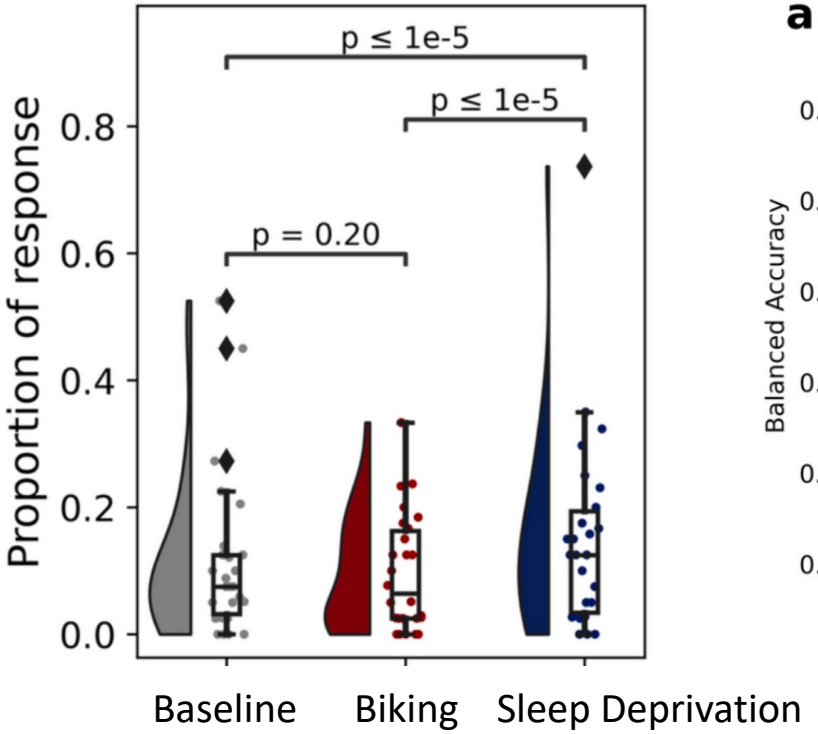


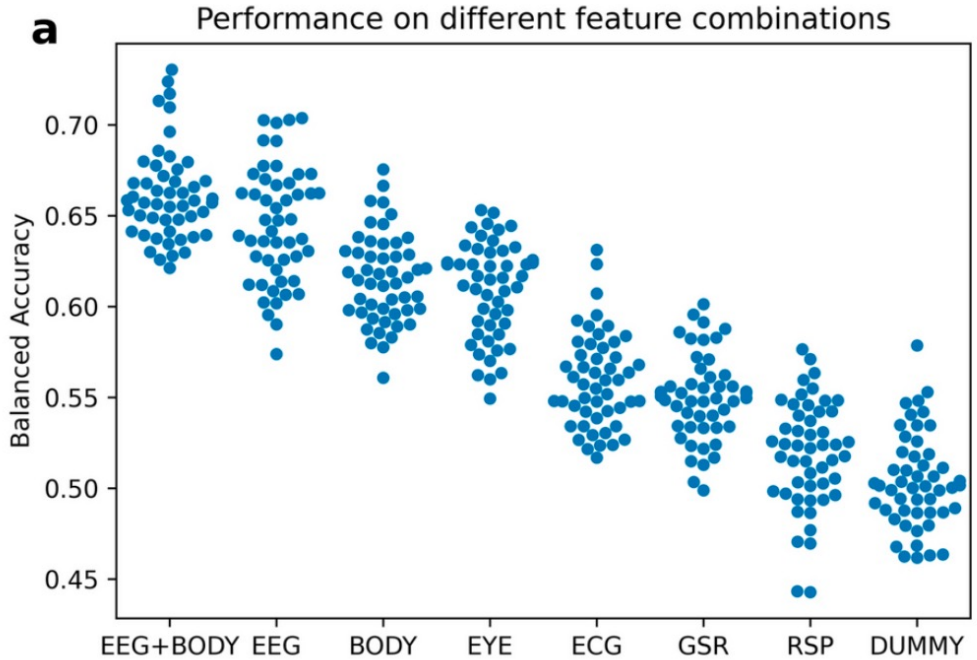

**"Hyperconnectivity"**




Mortaheb, Van Calster, Raimondo, Klados, Boulakis, Georgoulaa, Majerus, Van De Ville*, Demertzi*. ***PNAS*** 2022

# Altered arousal increases MB reports

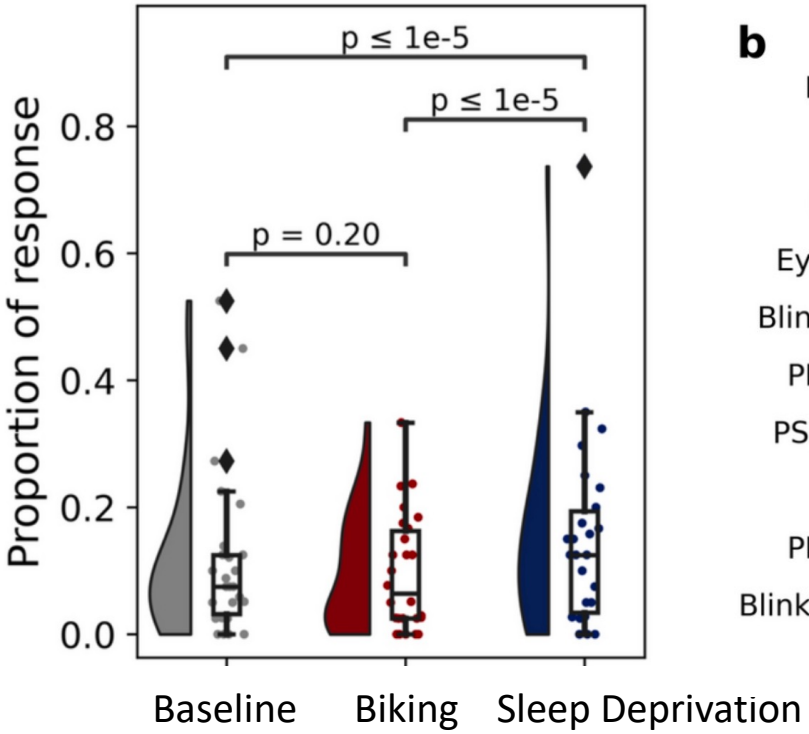


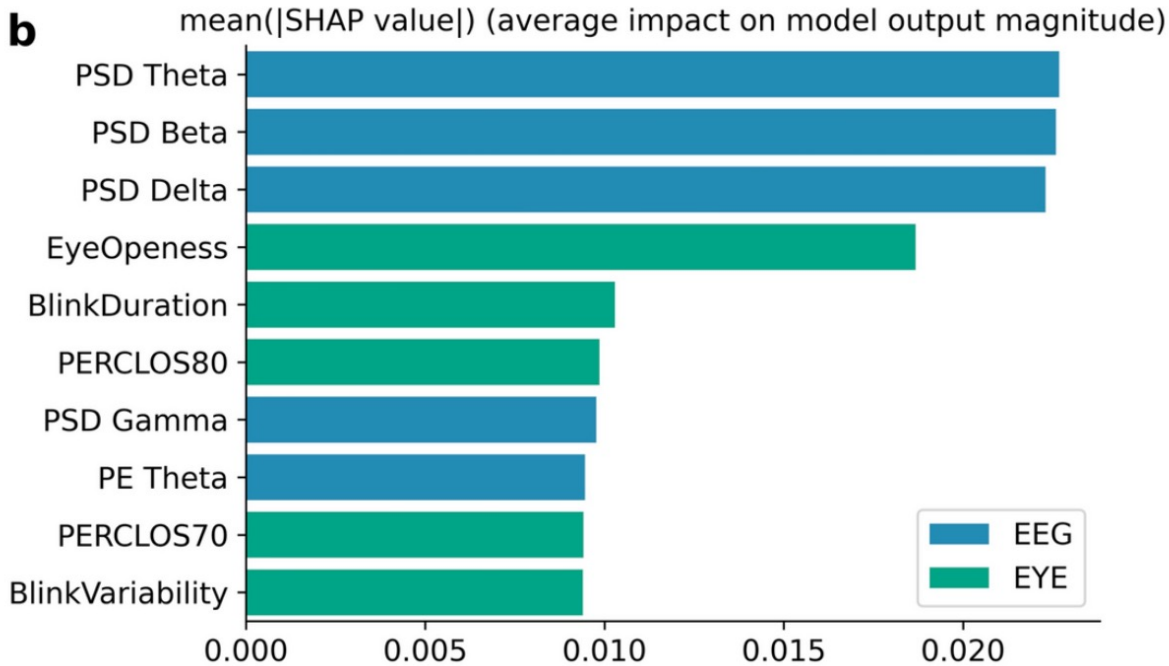




***but*** MB was more frequent in
first half of post-exercise vs. second half

Boulakis, Simos, Zoi, Mortaheb, Schmidt, Raimondo, Demertzi. ***Sci Rep*** 2025

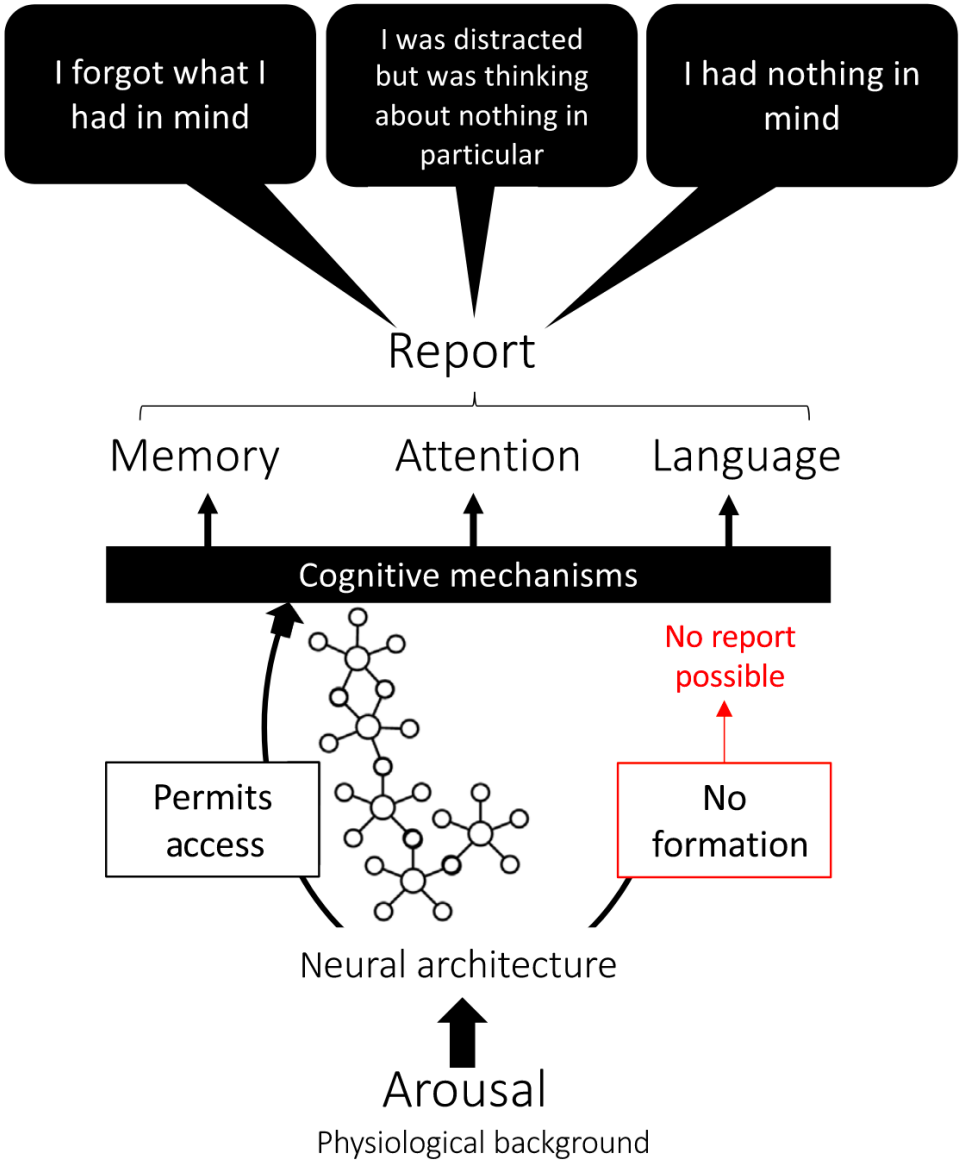
# Altered arousal increases MB reports




***but*** MB was more frequent in
first half of post-exercise vs. second half

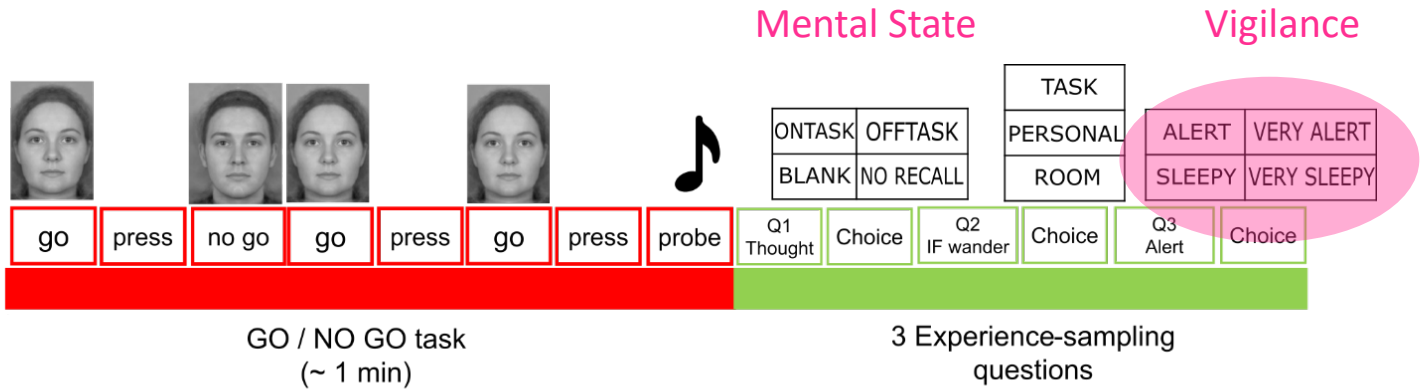
Boulakis, Simos, Zoi, Mortaheb, Schmidt, Raimondo, Demertzi. ***Sci Rep*** 2025

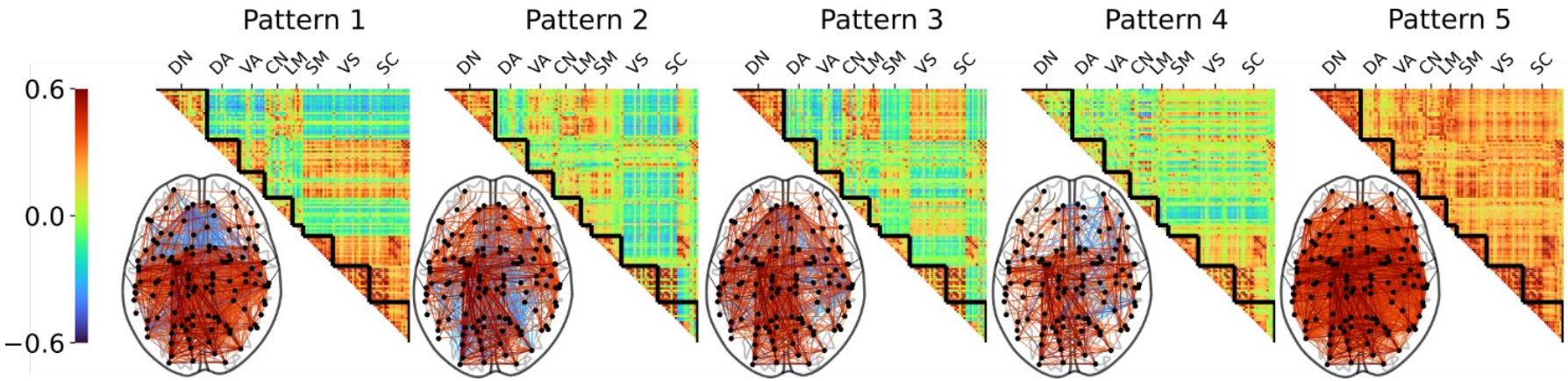



# A physio-cognitive account of the phenomenology of MB

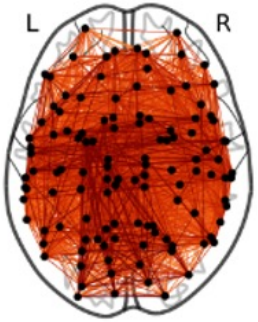
Andrillon, Lutz, Windt, Demertzi. ***Trends Cogn Sci*** 2025

# Different MB types?



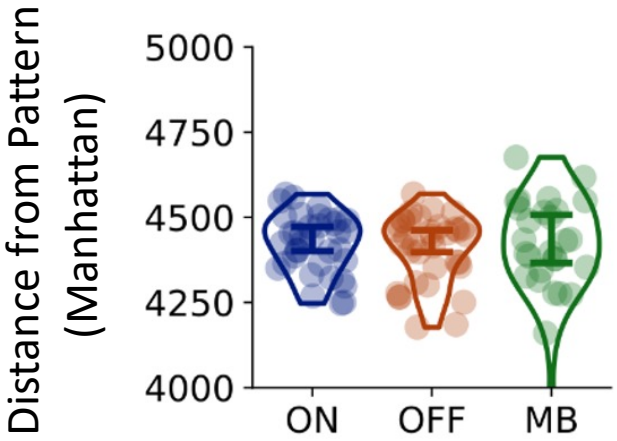




Boulakis, Kusztor, Tsuchiya, Andrillon, Demertzi. ***In prep***

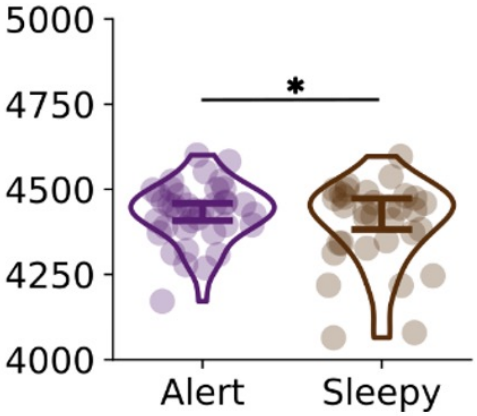



# MB-related patterns depend on vigilance levels

No evidence for a relationship between hyperconnectivity-MB

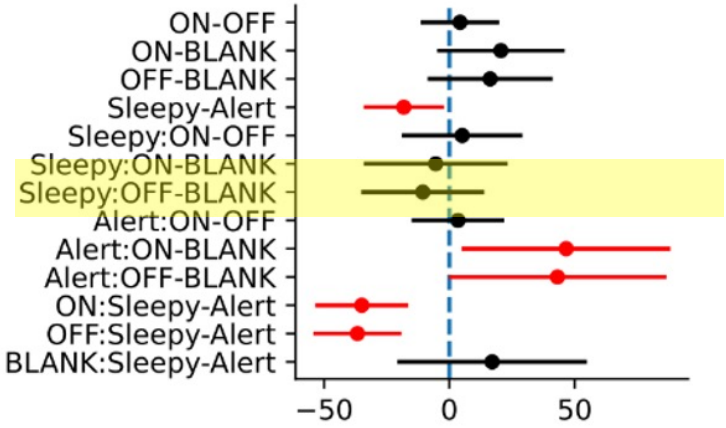



Hyperconnectivity closer to Sleepy




Interaction

When ALERT, MB reports are closer to Hyperconnectivity

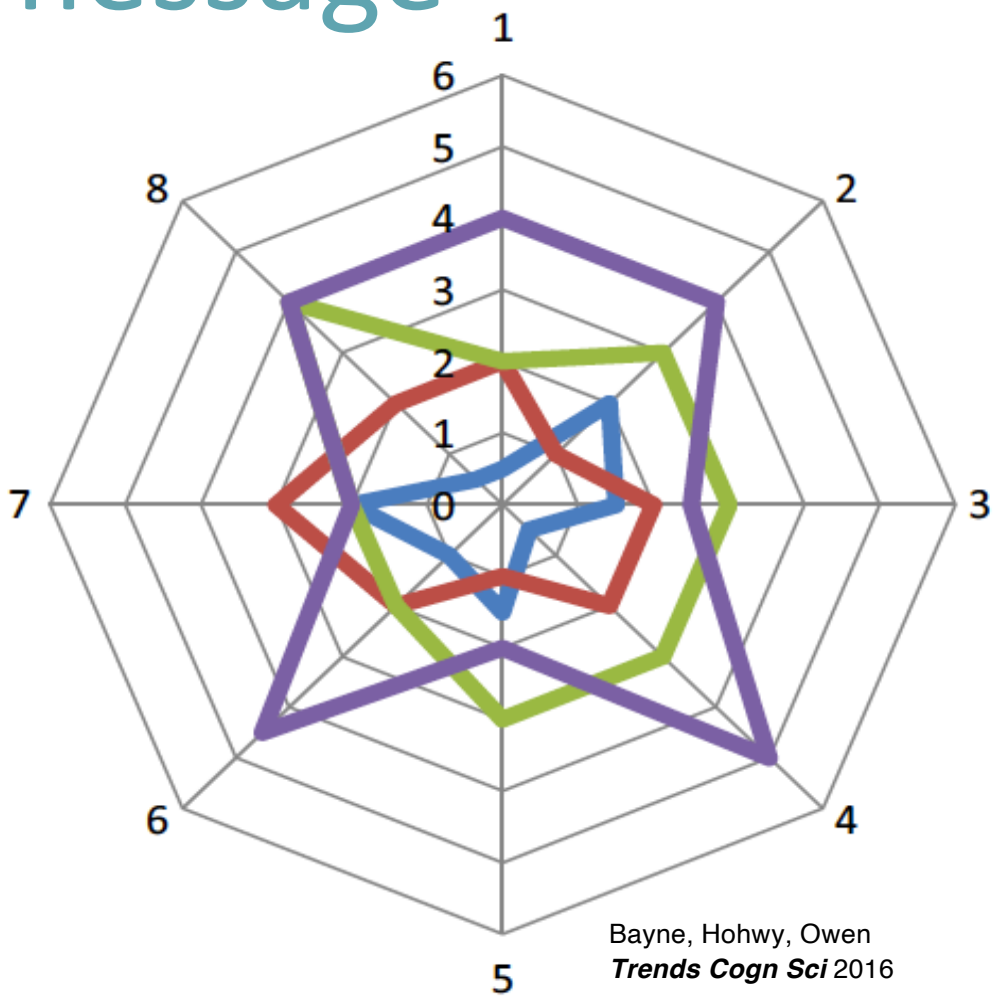



Boulakis, Kusztor, Tsuchiya, Andrillon, Demertzi. ***In prep***

# Take-home message

## Network Neuroscience

* Insights into pathological conditions
* Insights into dimensions of consciousness
* Insights into mechanisms of wakefulness




Bayne, Hohwy, Owen
***Trends Cogn Sci*** 2016

# Attend!


# Submit!

Physiology of Cognition Lab

## COLLABORATORS

Federico RAIMONDO (FZ Jülich)
Sepehr MORTAHEB
Matthieu KOROMA
Christina SCHMIDT
Christine BASTIN
Christophe PHILLIPS
Gilles VANDEWALLE
Fabienne COLLETTE

## INTERNATIONAL COLLABORATORS

Thomas ANDRILLON
Jenny WINDT
Antoine LUTZ
Aniko KUSZTOR
Kristian SANDBERG
Timo Torsen SCHMIDT
Marzia DE LUCIA
Andria PELENTRITOU
Christine BLUME
Jan REMAEKERS
Natasha MASON
Pablo MALLARONI

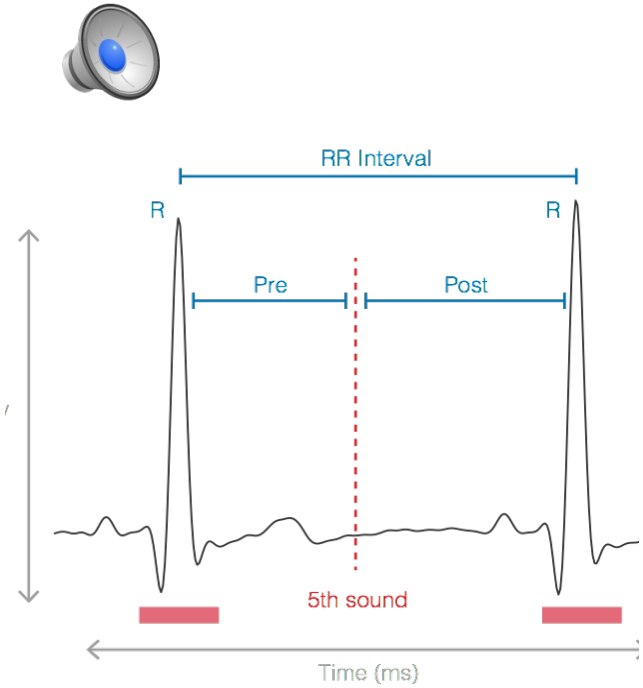
# Cardiac reactions to oddballs in MCS

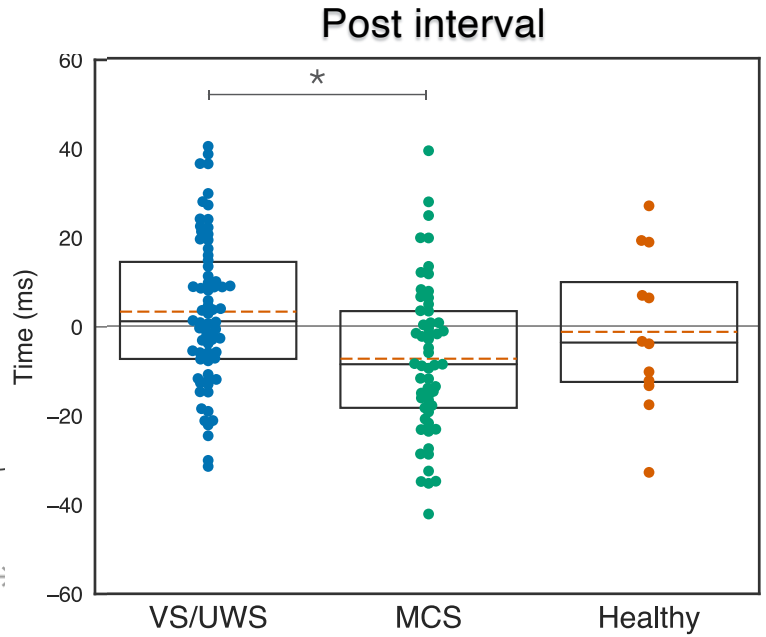
Auditory oddball paradigm

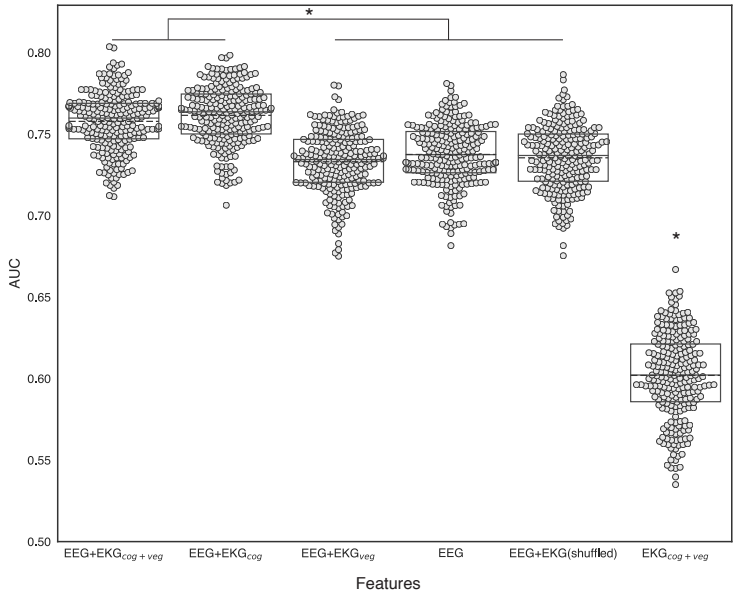
*Bekinschtein et al.*, PNAS, 2009

**Cardiac cycle-phase acceleration only in MCS**

Electrocardiographic markers carry independent information from EEG

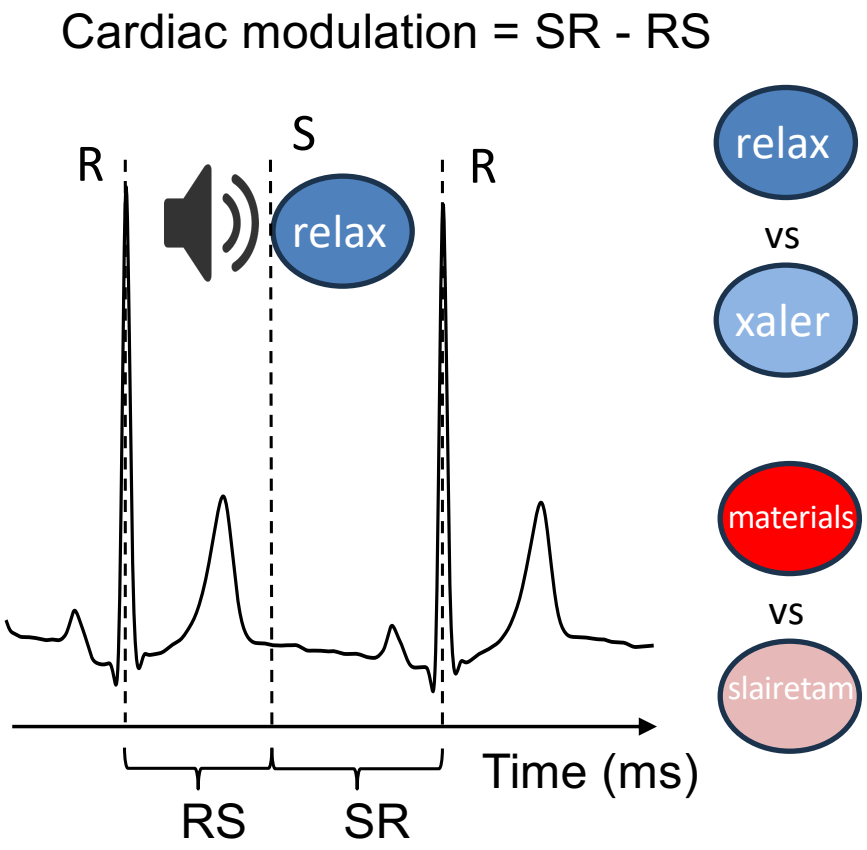


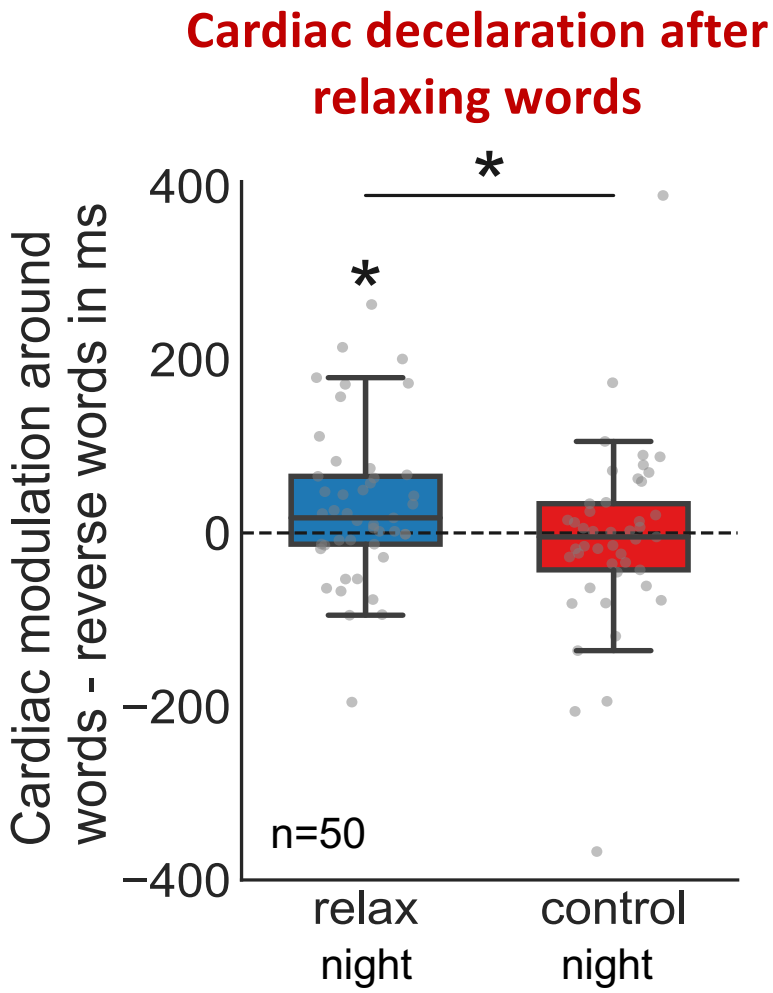




Raimondo, Rohaut, Demertzi, Valente, Engemann, Salti, Fernandez Slezak, Naccache, Sitt. *Annals of Neurology* 2017

# Cardiac responses to word-induced relaxation during sleep



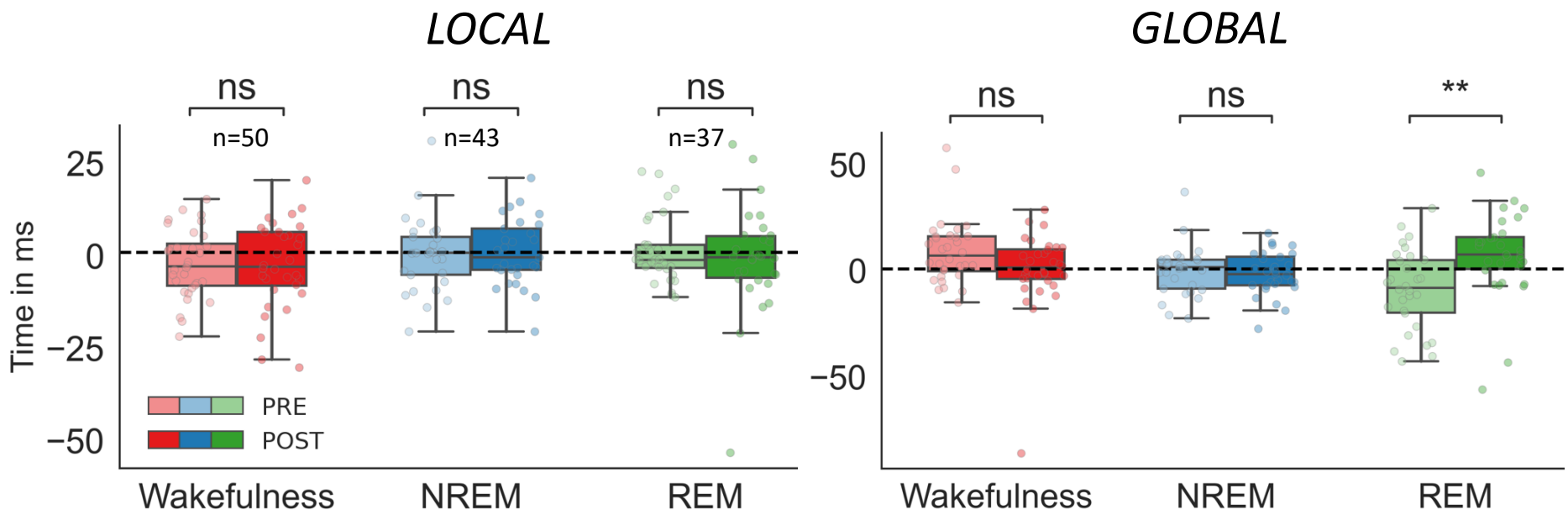




Koroma, Beck, Schmidt, Rasch, Demertzi, A. ***J Sleep Res*** 2024

# Cardiac reactions to oddballs in <u>sleep</u>

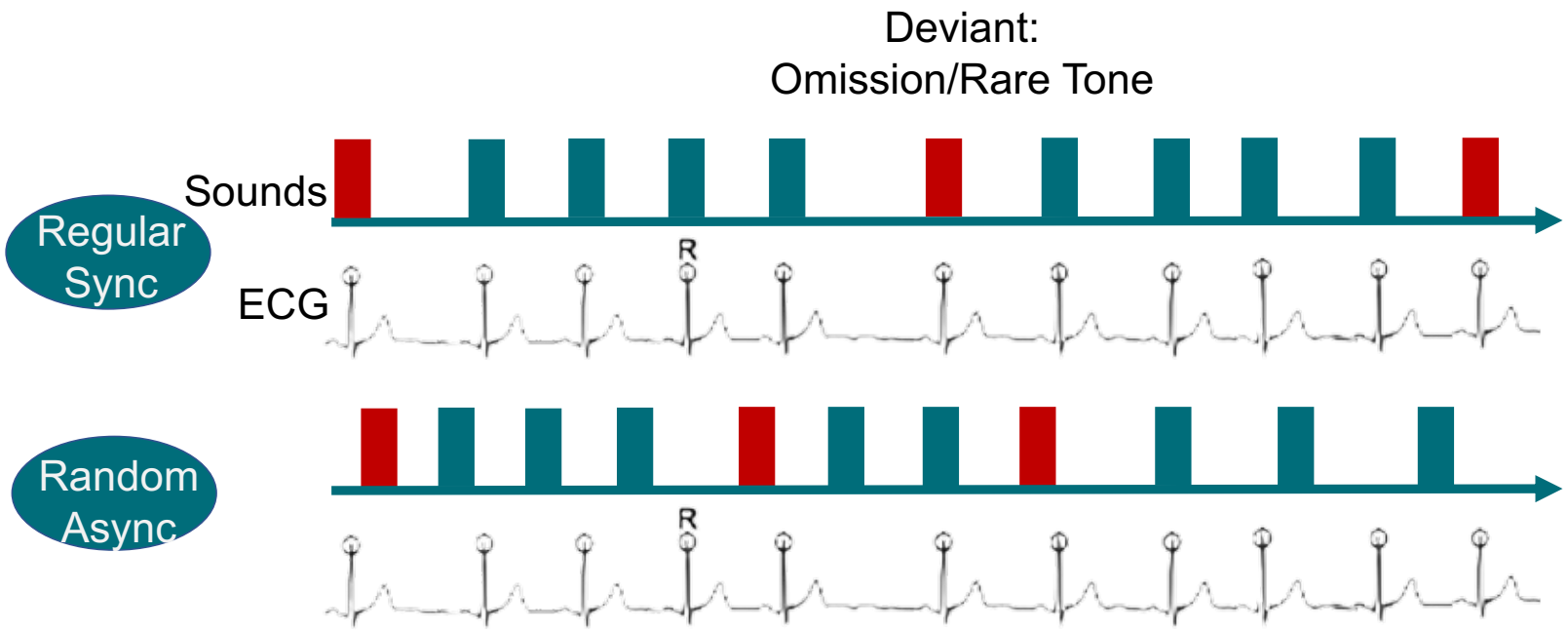
**EEG:** Strauss, Sitt, King, Elbaz, Azizi, Buiatti, Naccache, van Wassenhove, Dehaene, S, *PNAS* 2015
**EEG**: Blume, Niedernhuber, Spitschan, Slawik, Meyer, Bekinschtein, & Cajochen. *Sleep* 2022

**Cardiac deceleration for global deviants only in REM**




Koroma, Boulakis, Raimondo, Blume, Strauss, Demertzi. *In prep*

# Cardiac responses to omitted sounds presented in synchrony to heartbeats




Cardiac deceleration for sound omissions and rare tones in synchronous condition only

Koroma, Nguy, Pelentritou, De Lucia, Demertzi. *In prep*
Pelentritou, Pfeiffer, Schwartz, De Lucia. *Comm Biology* 2024