Functional High-Definition Imaging of EEG Brain Dynamics

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University of California San Diego

13th EEGLAB Workshop

Aspet, France

June 2011

Swartz Center for Computational Neuroscience

Arnaud Delorme

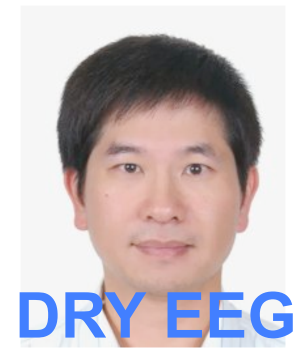
Christian Kothe

David Groppe

Jason Palmer

Julie Onton

Tim Mullen



Tzyy-Ping Jung

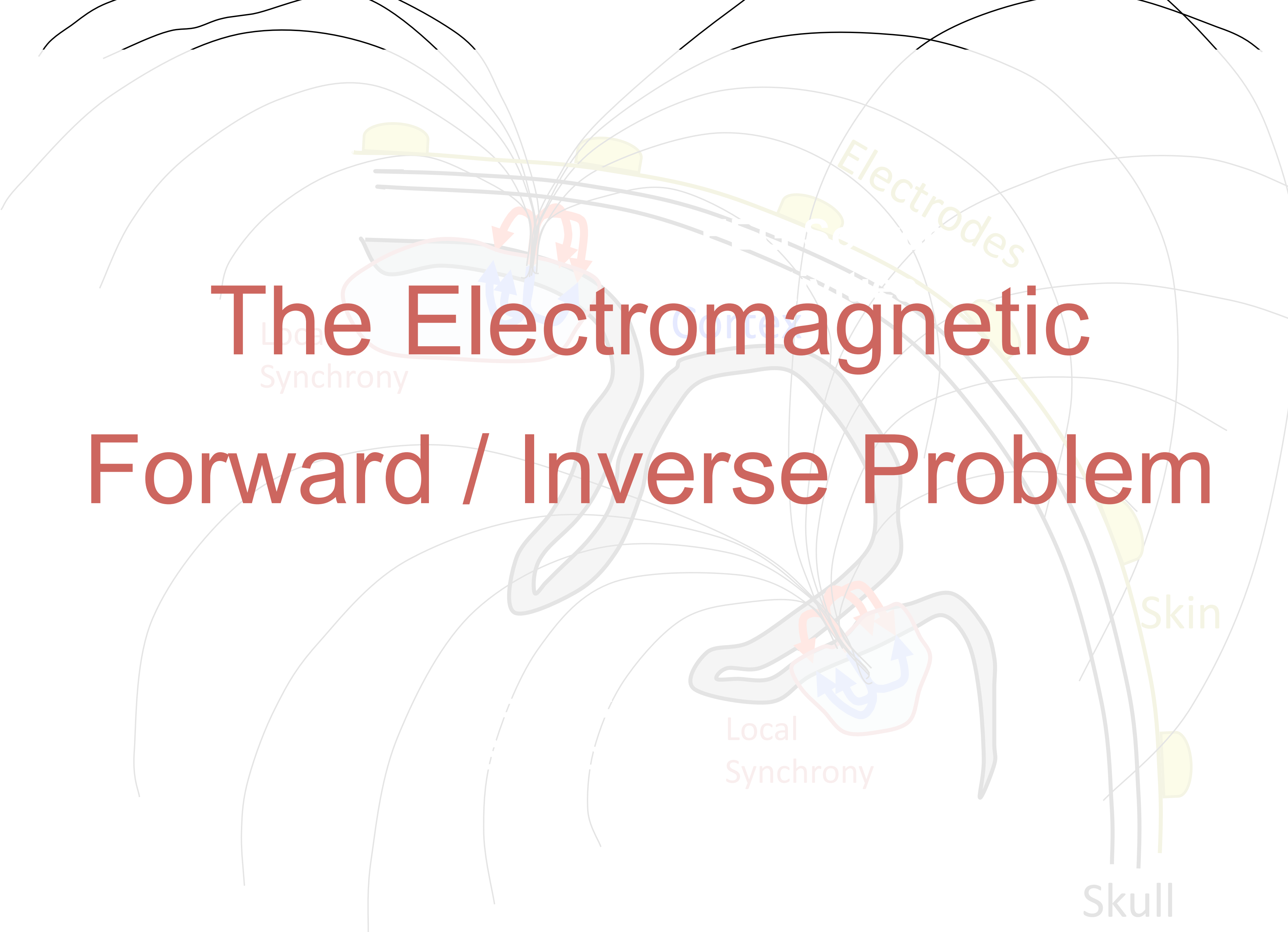
Alejandro Ojeda

Tony Bell

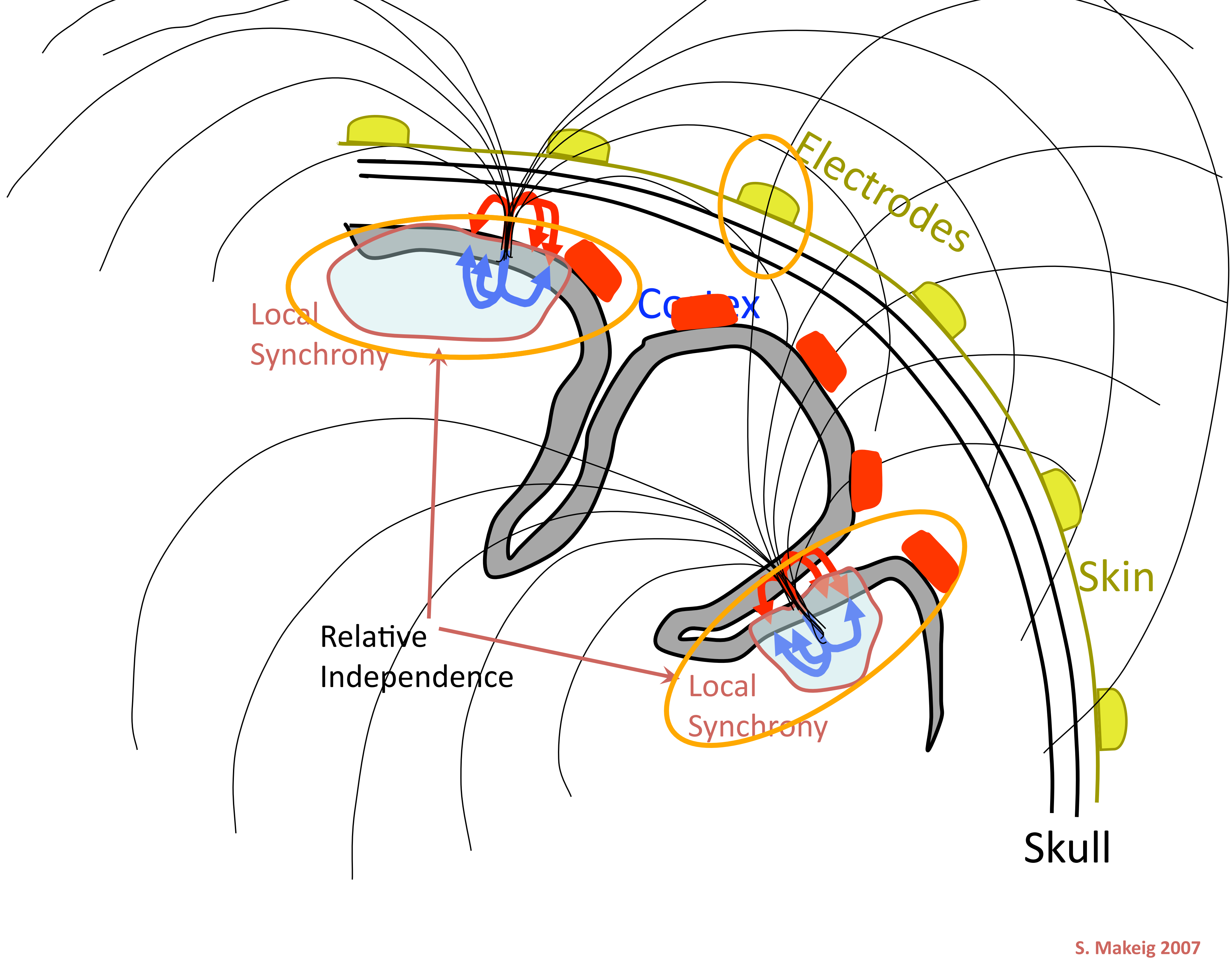
Zeynep Akalin Acar

Nima Bigdely Shamlo

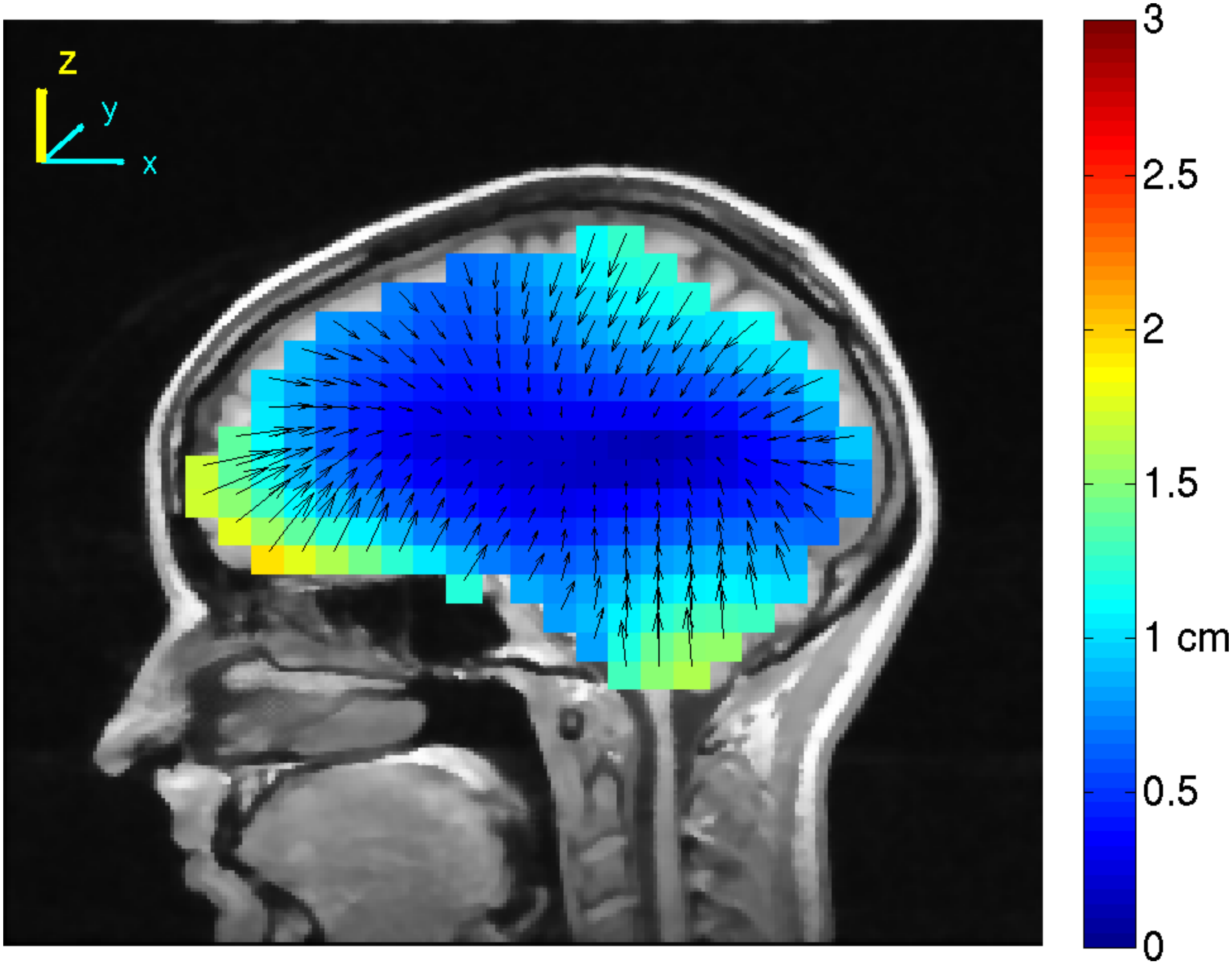
The Electromagnetic Forward / Inverse Problem



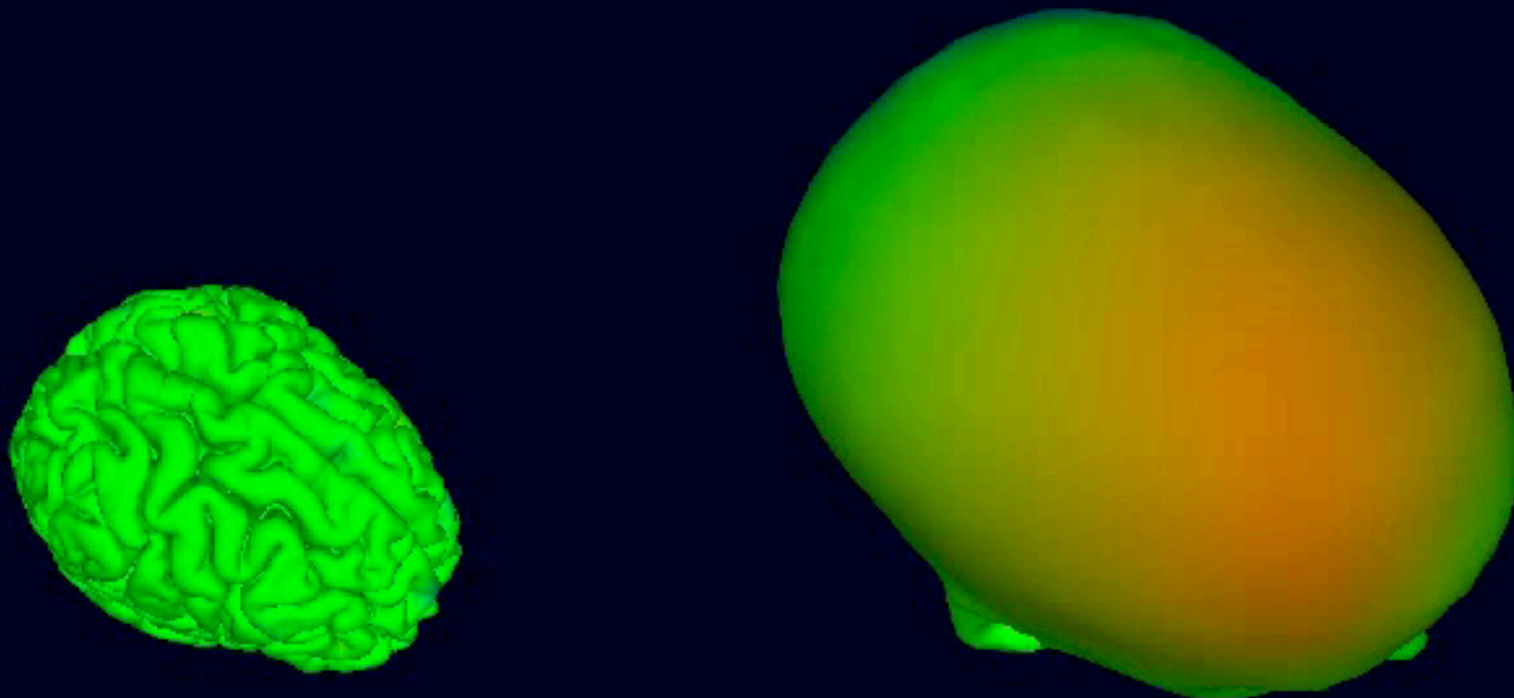

Phase cones (Freeman)
Avalanches (Plenz)
S. Makeig 2007


Electrodes
Cortex
Local
Synchrony
Relative
Independence
Local
Synchrony
Skin
Skull
S. Makeig 2007

Electromagnetic source localization using realistic head models→ The NFT toolbox

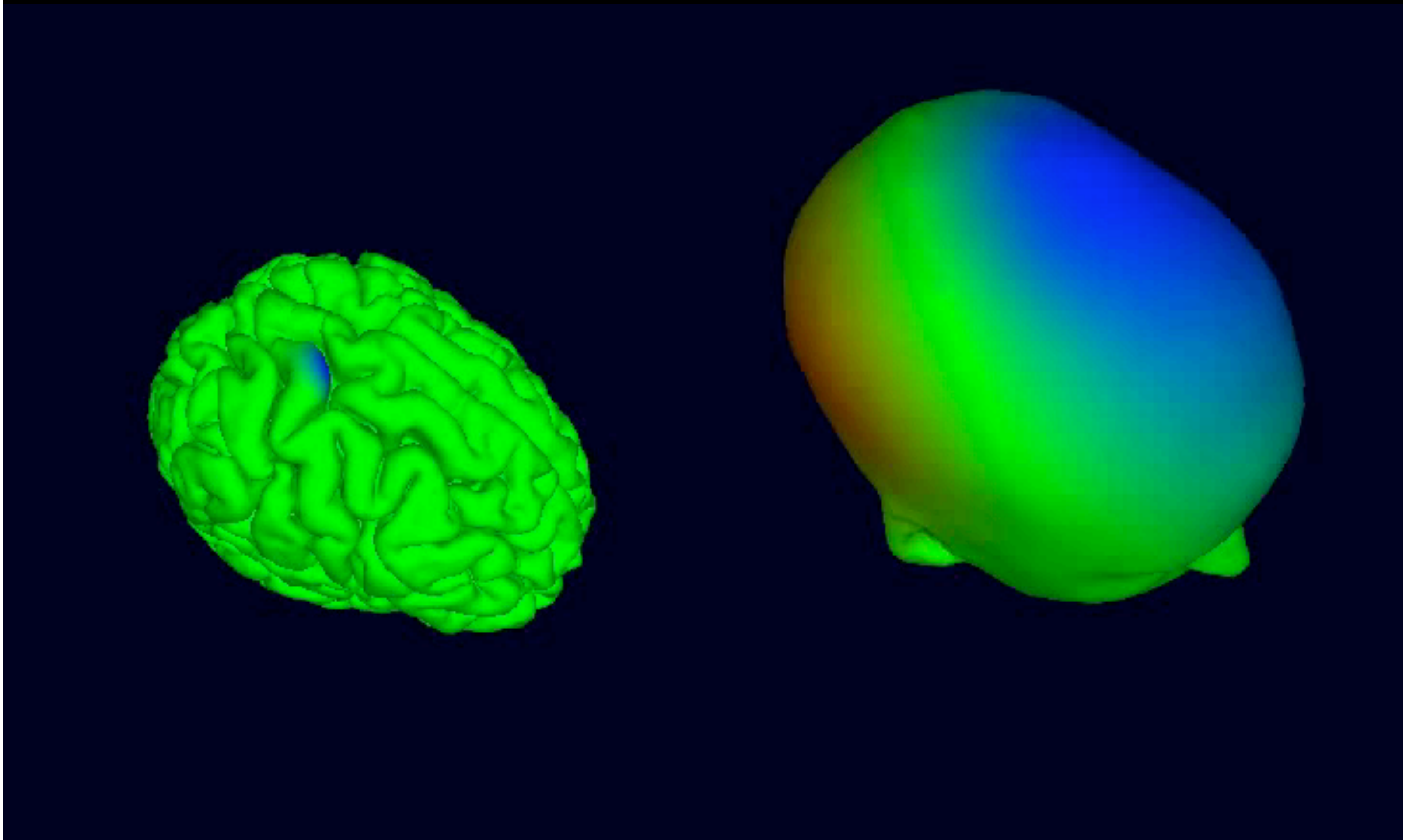


The very broad EEG point-spread function



Akalin Acar & Makeig 2010

The very broad EEG point-spread function

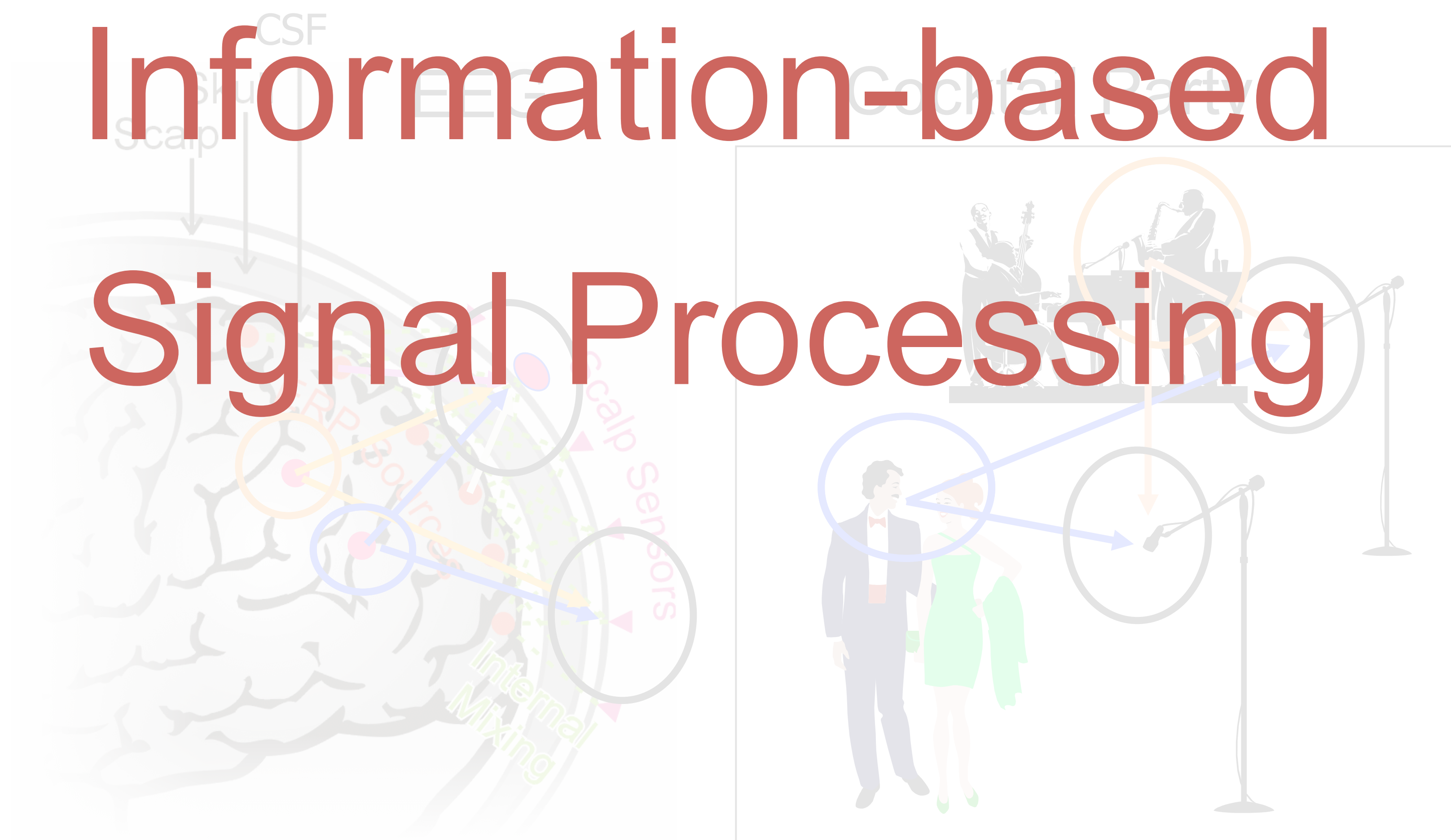


Simulated spatially labile (traveling wave) parietal source activity

Akalin Acar & Makeig 2010

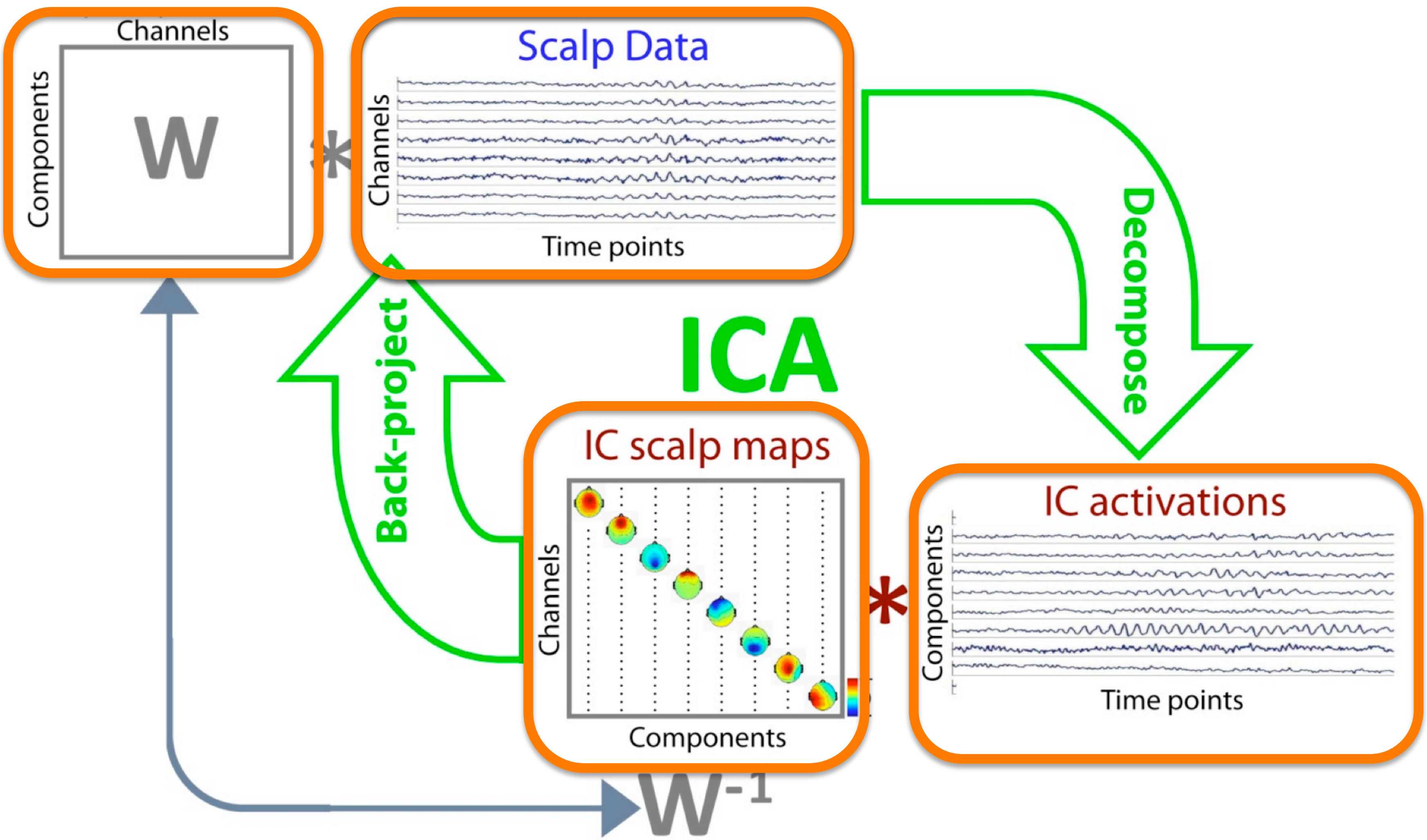
Blind EEG Source Separation by ICA

Information-based Signal Processing



S. Makeig 2010

ICA is a linear decomposition



S. Makeig 2010

Independent Component Analysis of Electroencephalographic Data

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Abstract

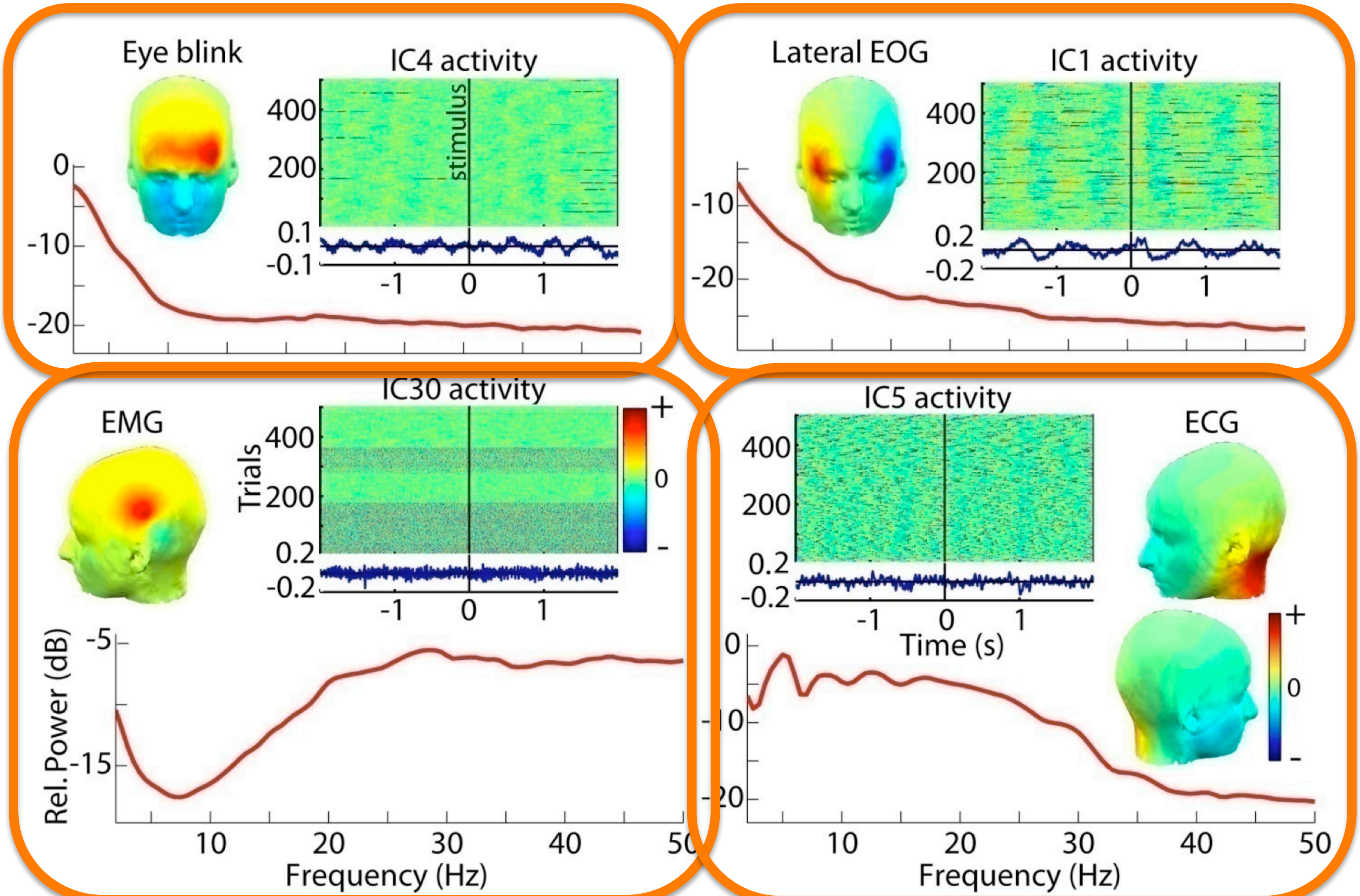
Because of the distance between the skull and brain and their different resistivities, *electroencephalographic* (EEG) data collected from any point on the human scalp includes activity generated within a large brain area. This spatial smearing of EEG data by volume conduction does not involve significant time delays, however, suggesting that the *Independent Component Analysis* (ICA) algorithm of Bell and Sejnowski [1] is suitable for performing blind source separation on EEG data. The ICA algorithm separates the problem of source identification from that of source localization. First results of applying the ICA algorithm to EEG and *event-related potential* (ERP) data collected during a sustained auditory detection task show: (1) ICA training is insensitive to different random seeds. (2) ICA may be used to segregate obvious artifactual EEG components (line and muscle noise, eye movements) from other sources. (3) ICA is capable of isolating overlapping EEG phenomena, including alpha and theta bursts and spatially-separable ERP components, to separate ICA channels. (4) Nonstationarities in EEG and behavioral state can be tracked using ICA via changes in the amount of residual correlation between ICA-filtered output channels.

Makeig et al., NIPS, 1995

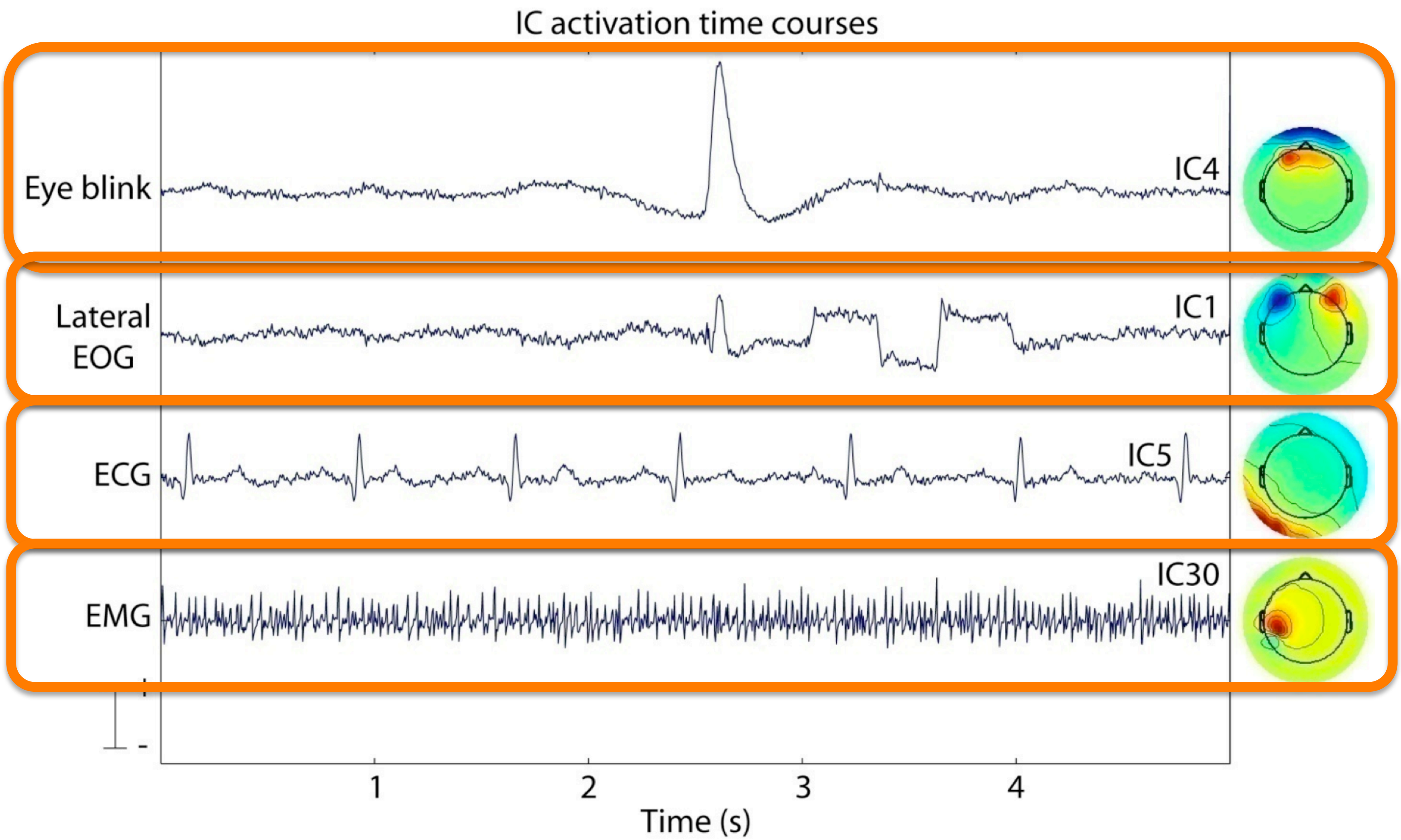
1

"ICA may be used to segregate obvious artificial EEG component (line and muscle noise, eye movements) from other sources."

- Makeig et al., 1996



J. Onton & S. Makeig 2006



J. Onton & S. Makeig 2006

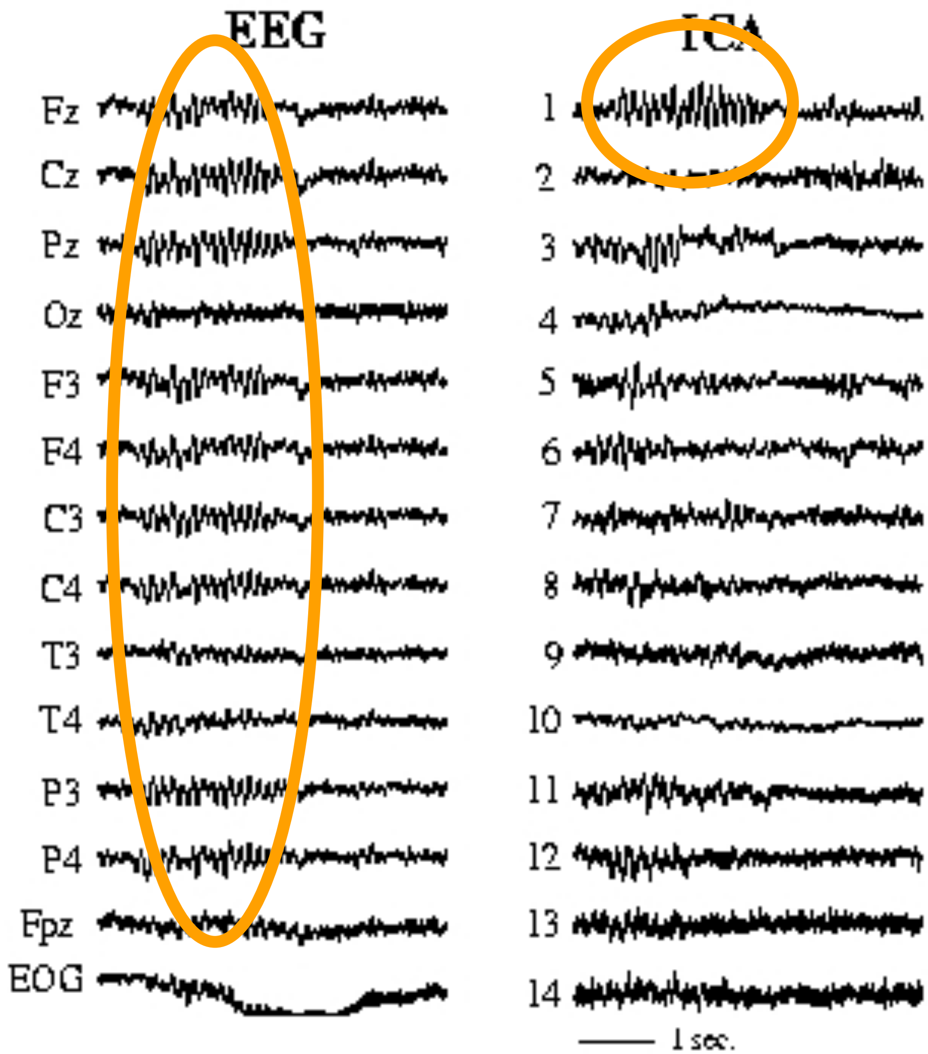


Figure 1: Left: 4.5 seconds of 14-channel EEG data. Right: an ICA transform of the same data, using weights trained on 6.5 minutes of similar data from the same session.

S. Makeig et al. (1995)

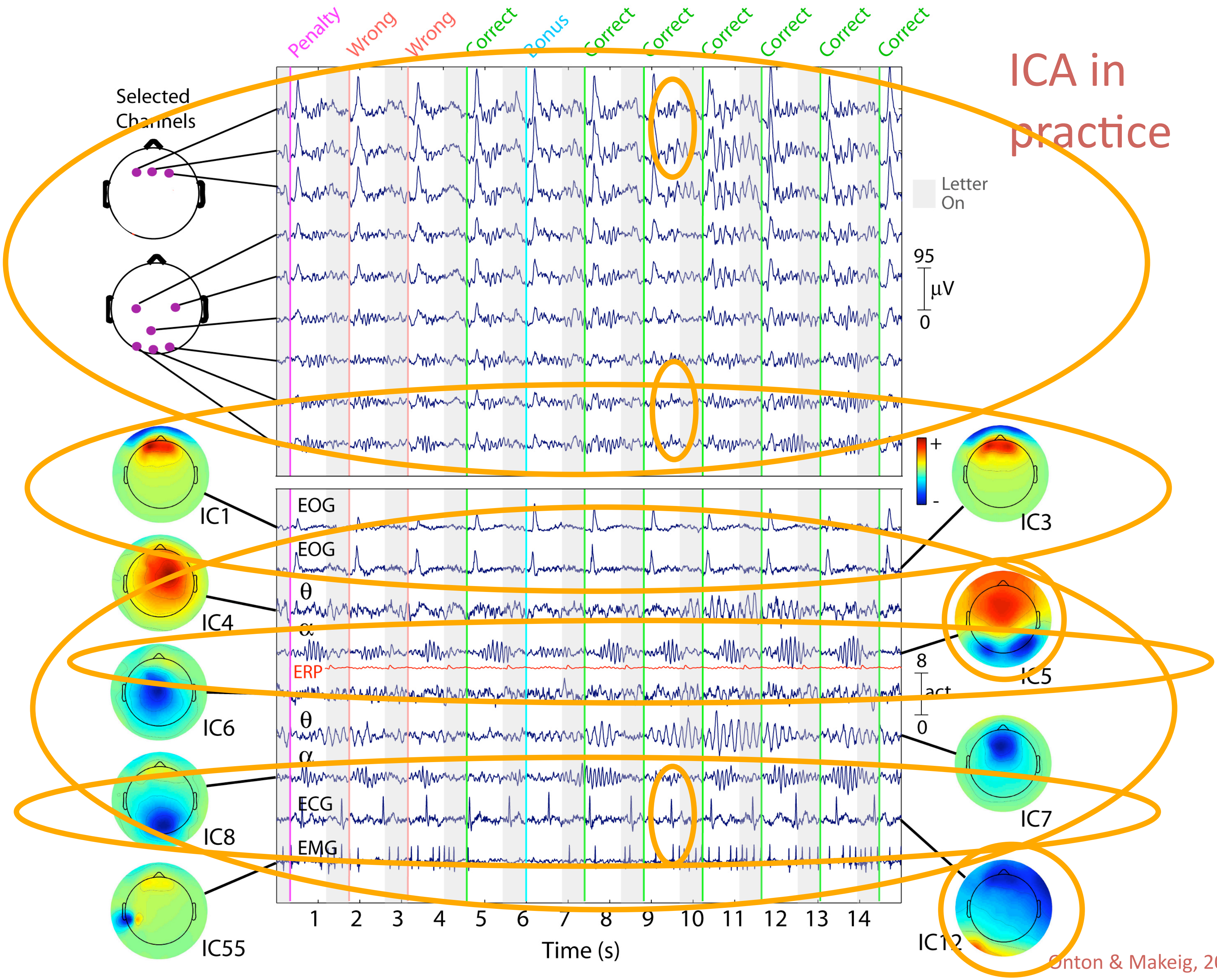
2

"ICA is capable of isolating overlapping EEG phenomena including alpha and theta bursts and spatially separable ERP components, to separate [ICs]."

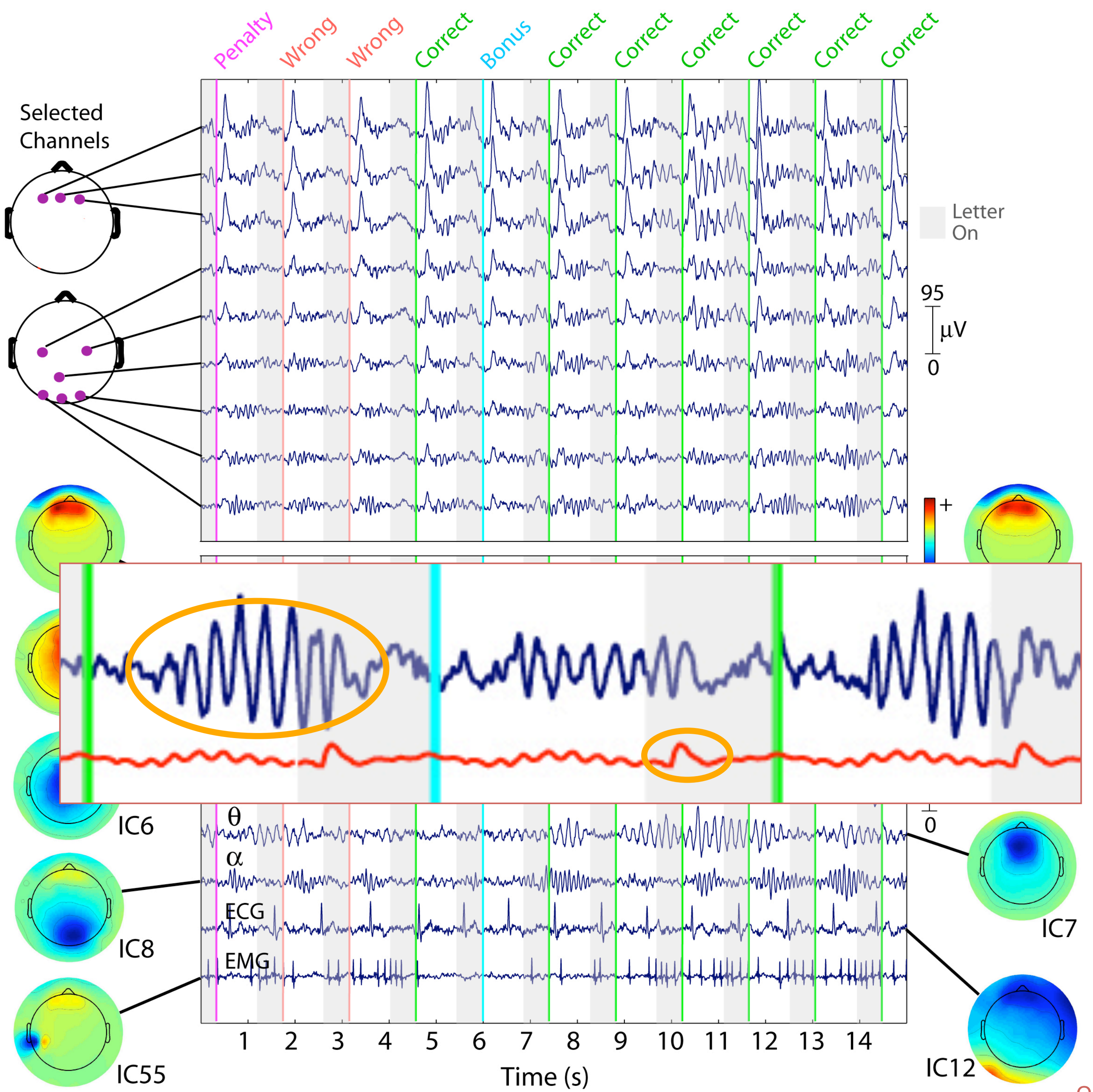
- Makeig et al., 1996

S. Makeig 2010

ICA in practice



Onton & Makeig, 2006



Onton, Makeig (2006)

3

"ICA training is insensitive to different random seeds,"

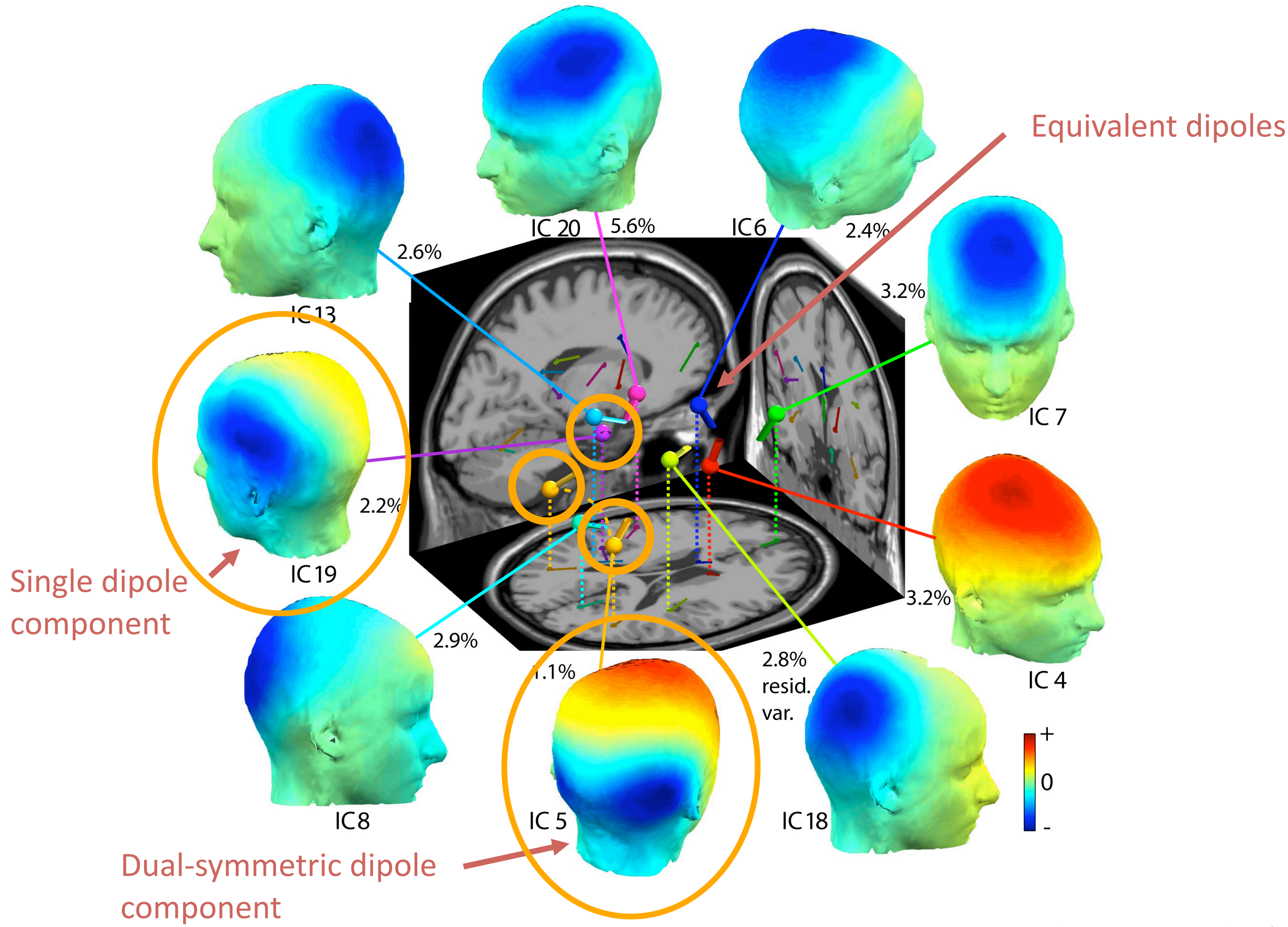
[... and can separate out independent components of data with hundreds of channels].

- Makeig et al., 1996

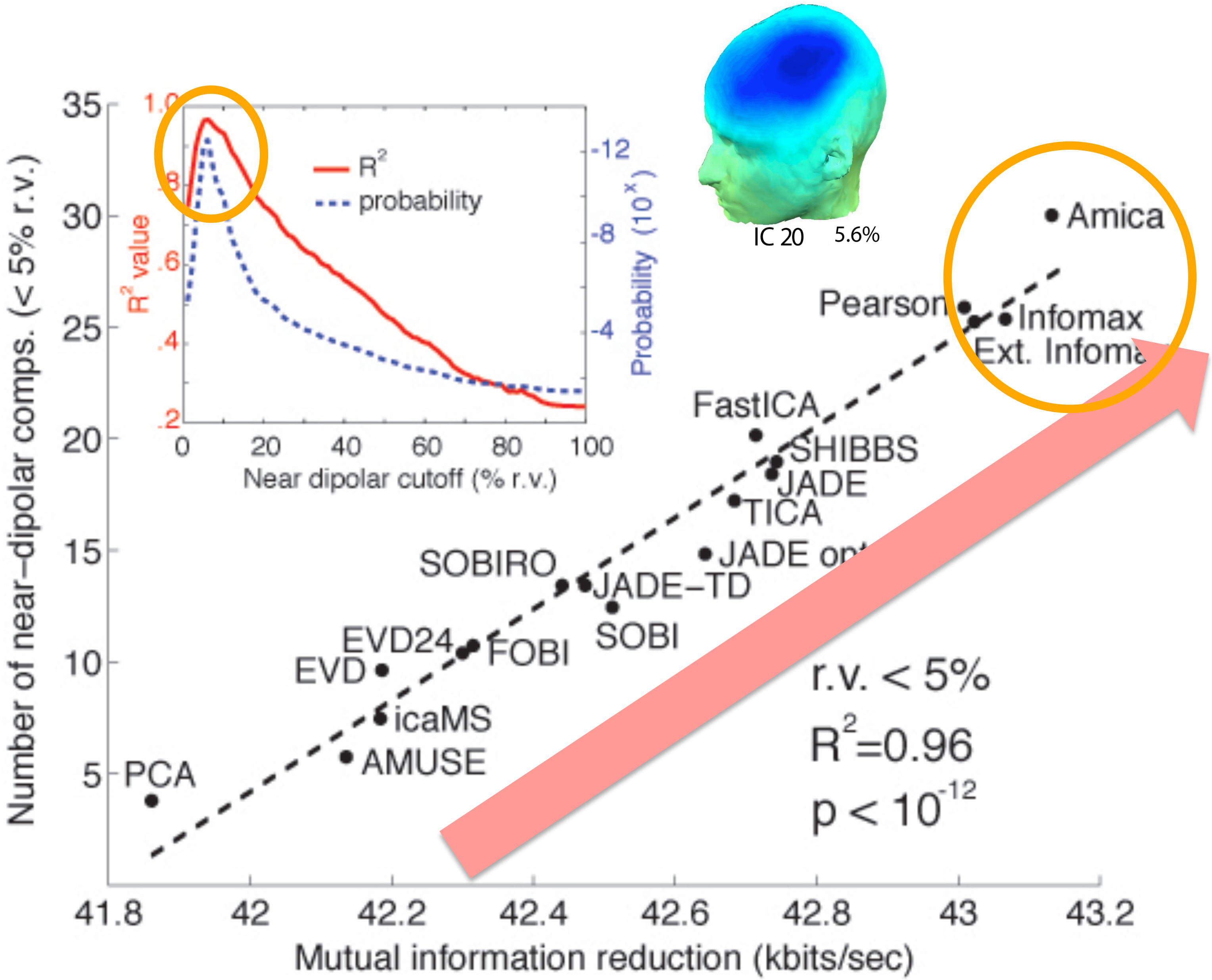
4

Brain-based, 'dipolar' independent components of EEG data are projections of single (dual) cortical patches.

Independent cortical components



Julie Onton & S. Makeig (2006)



A. Delorme, J. Palmer, S. Makeig, 2009

THUS → ICA (BSS) decompositions that

find components whose time courses are **more independent**

→ also find **more** components whose scalp maps are **'dipolar'**!

Thus, the two approaches to

constraining the EEG inverse problem,

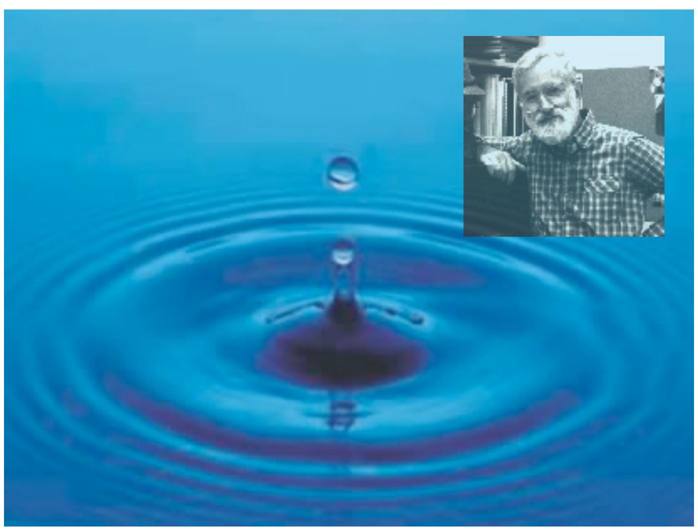
biophysical and ***statistical***,

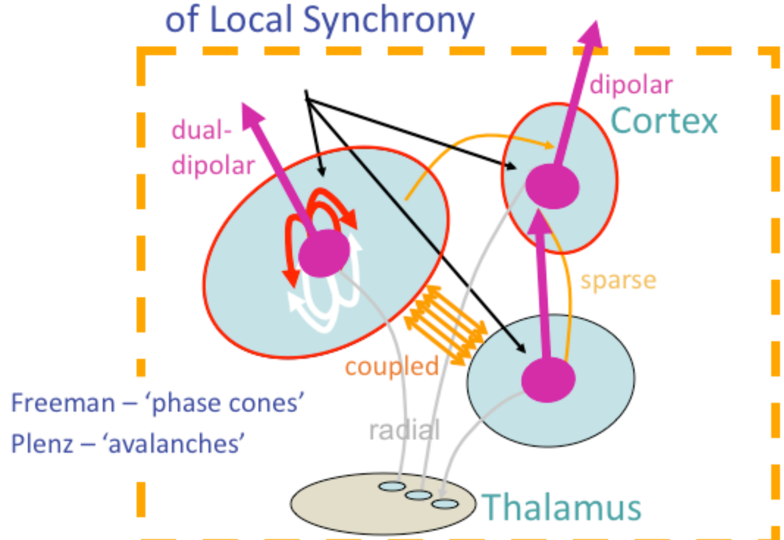
are directly interlinked.

S. Makeig, 2010

Why?

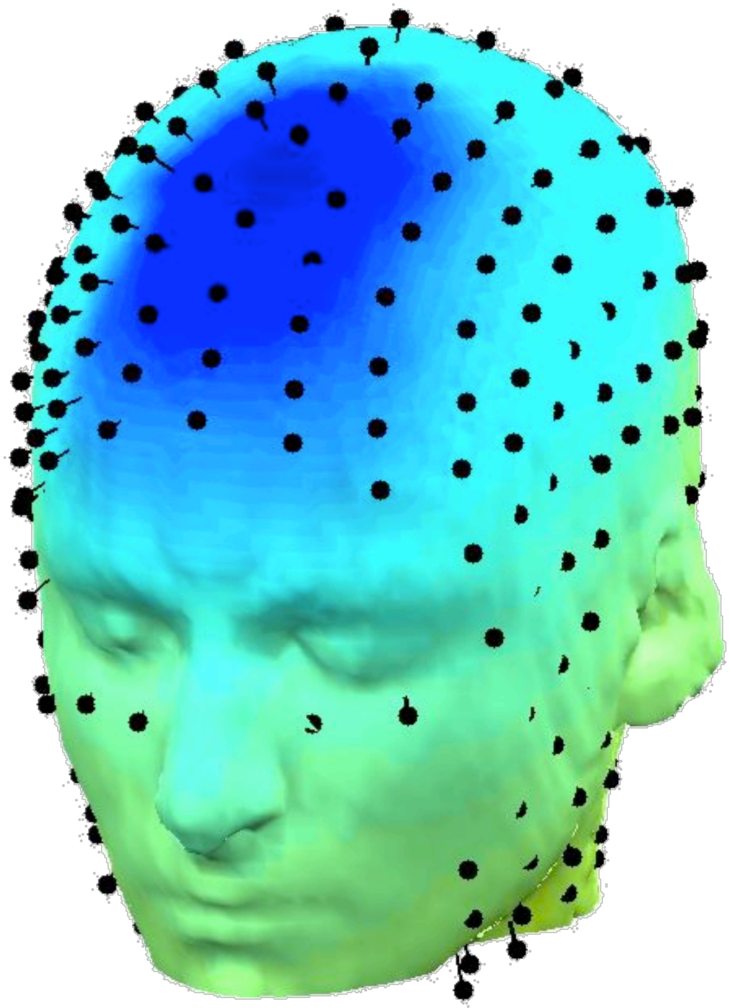
Very likely because the physiological assumptions motivating the use of ICA for EEG data are *substantially* correct...

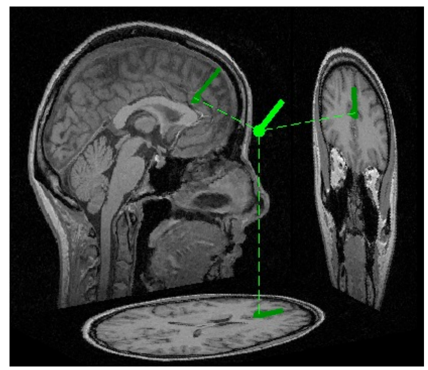


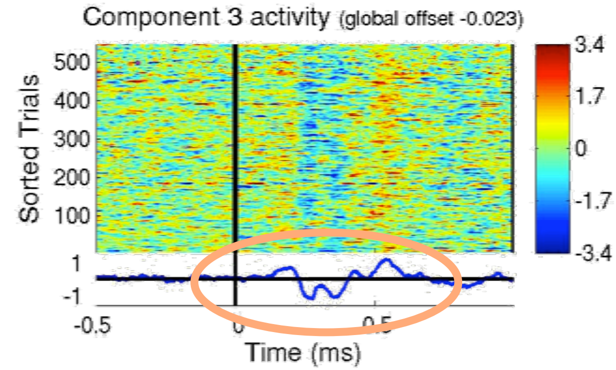


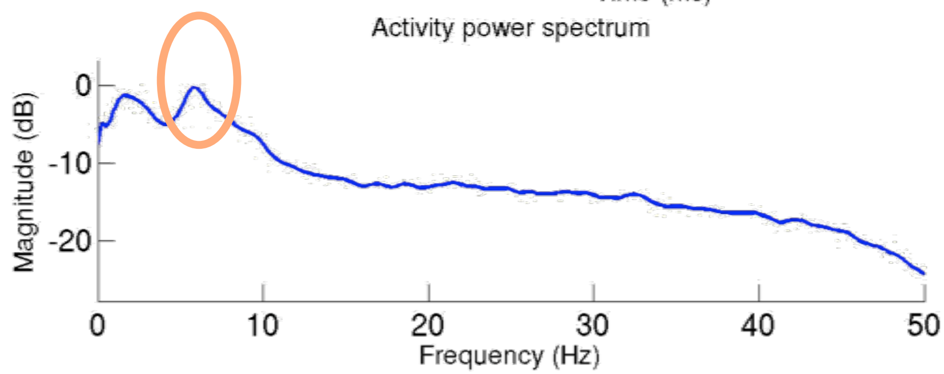
S. Makeig (2007)

Frontal Midline Theta Process

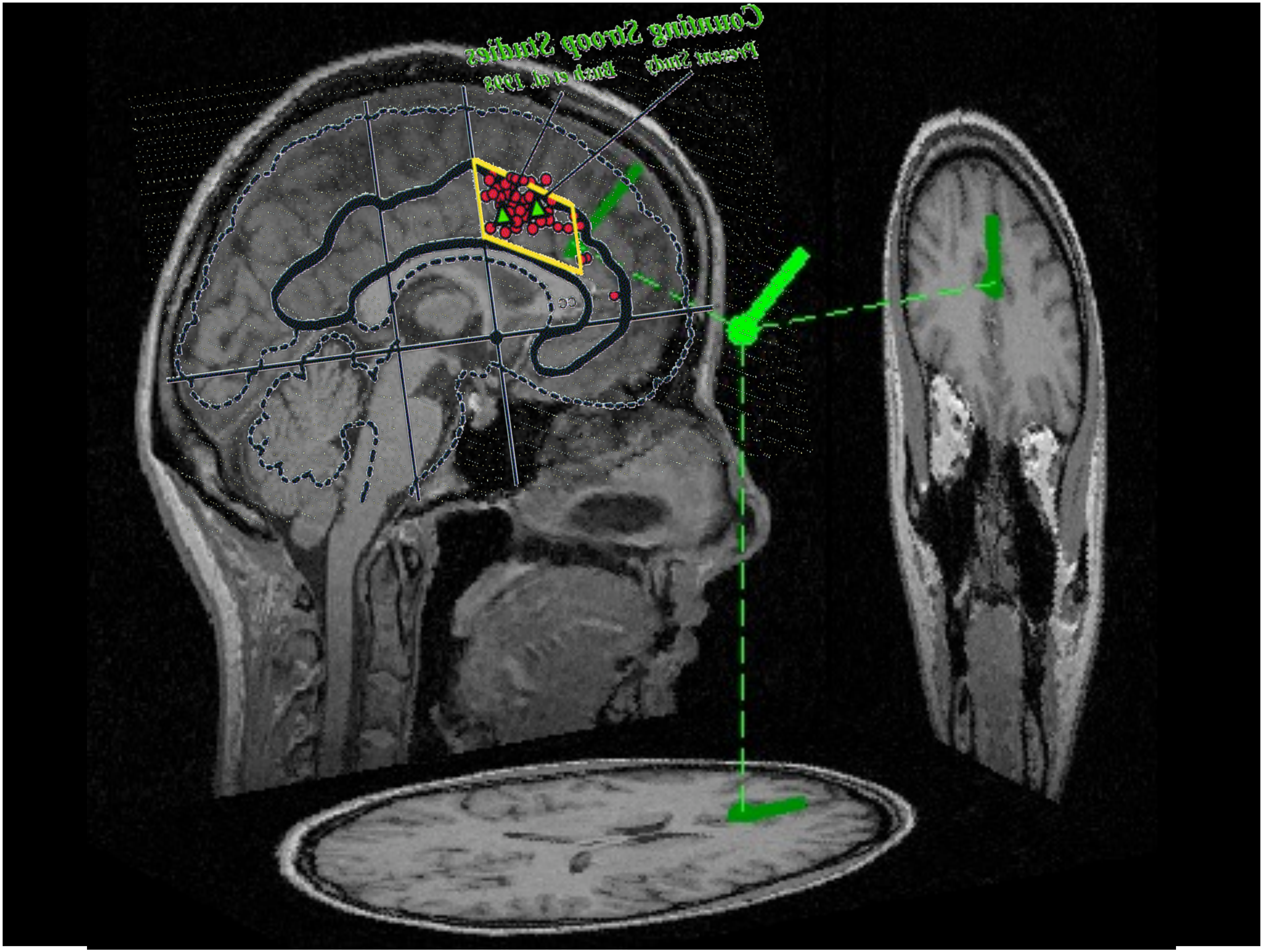




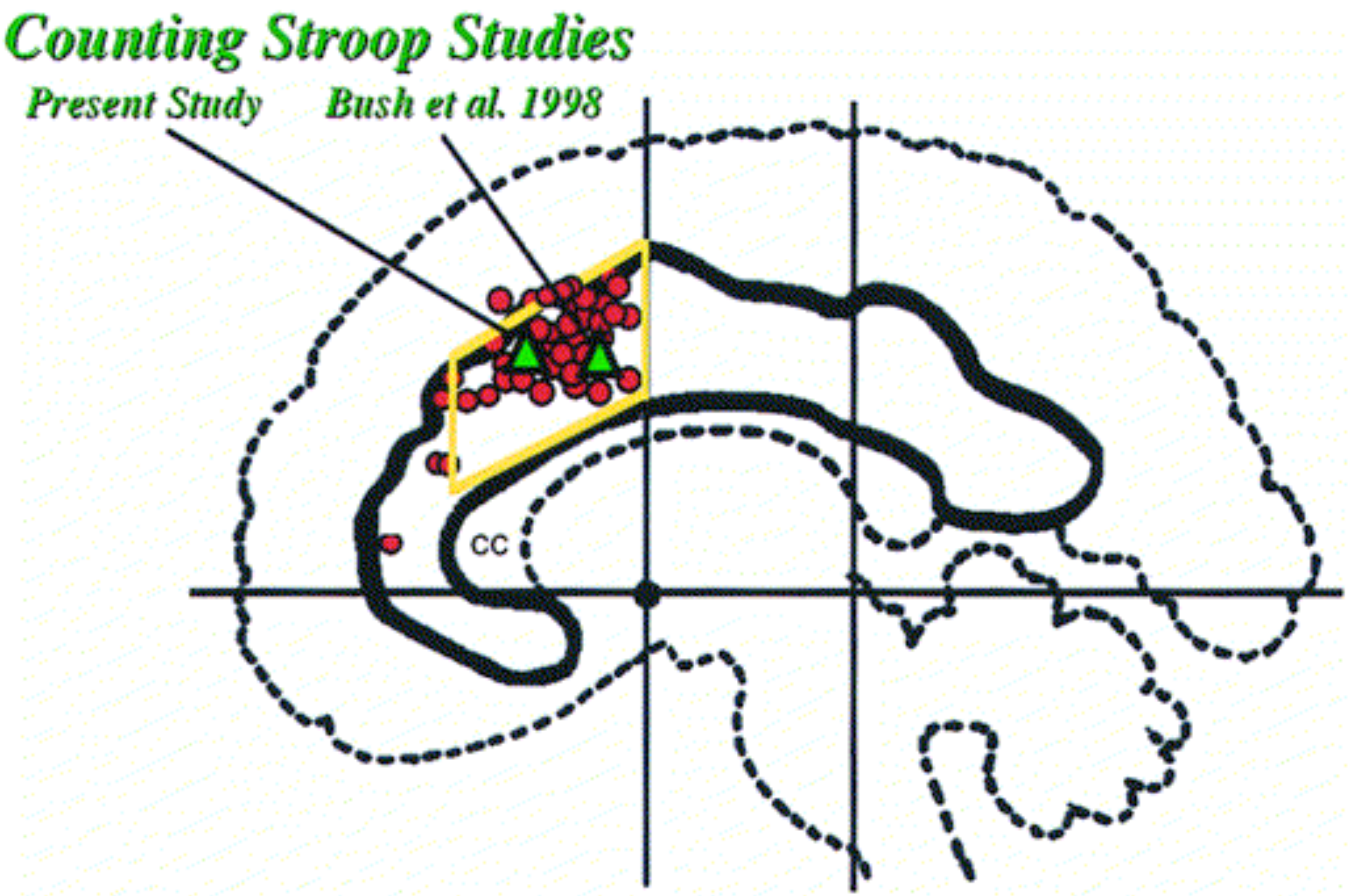




J. Onton & S. Makeig, 2005


Counting Stroop Studies
Present Study
Bush et al. 1998
cc

Anterior Cingulate Cognitive Division



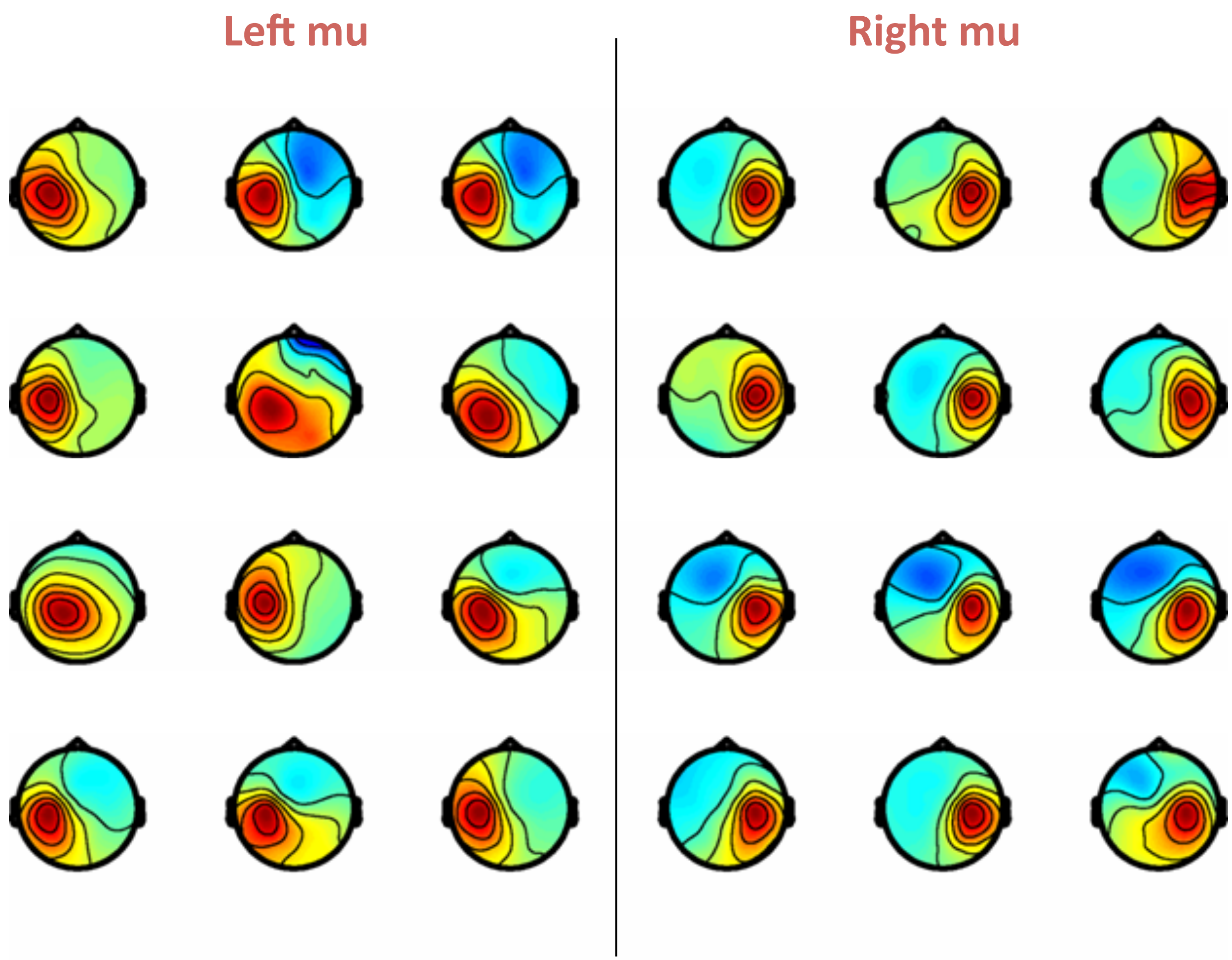
Bush et al., 1999

5

Similar independent components tend to reappear in different subjects performing the same task.

S. Makeig, 2007

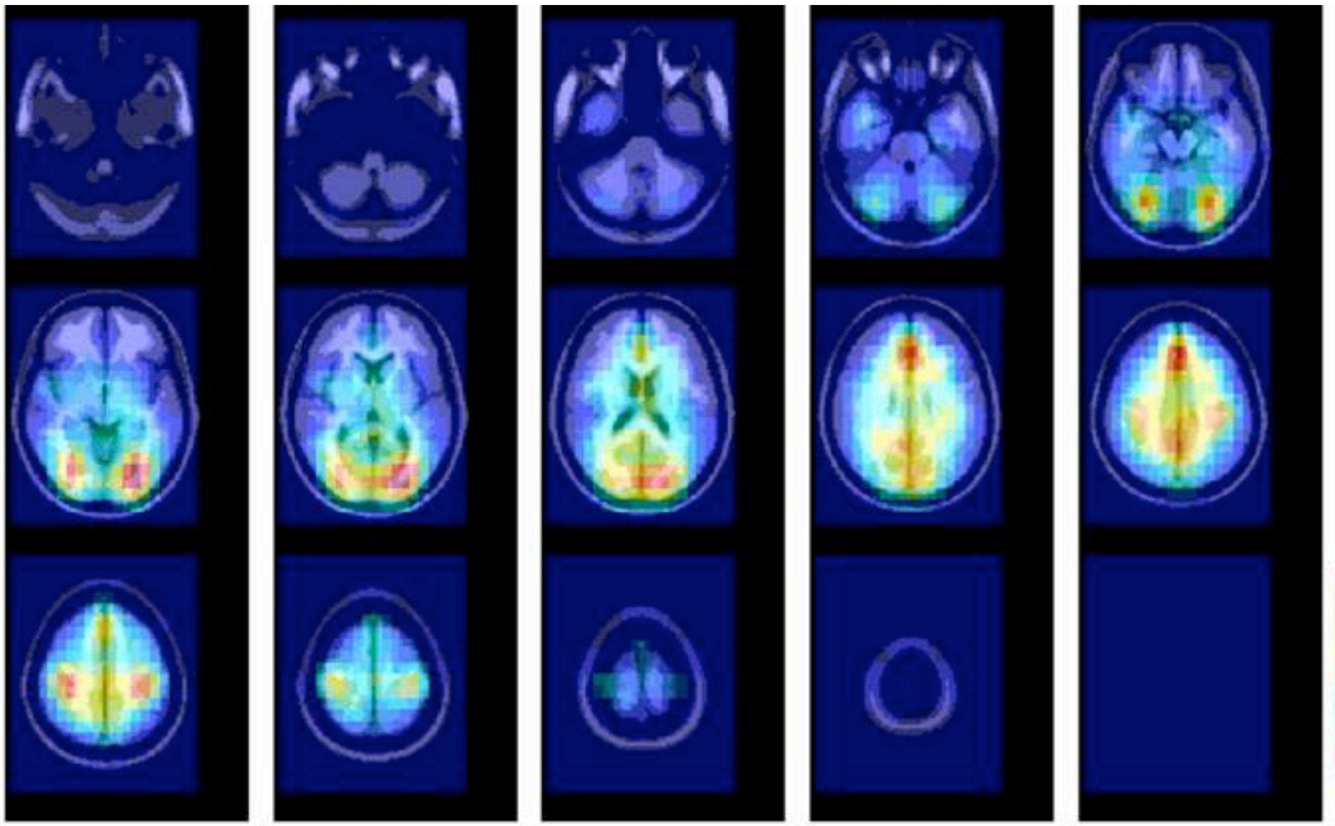
Clustering ICA components



S. Makeig 2003

Equivalent dipole density

Visual Working Memory



Sternberg letter memory task

Onton et al., 2005

Onton et al., '05

6

Independent components of EEG data tend to be **functionally** independent **–**

changes in their activity patterns tend to reflect **'top-down' changes** in **cognitive state** and/or **cognitive appraisal.**

S. Makeig, 2007

Embodied Cognition & Agency

Brain processes

have evolved and function

to optimize the ***outcome***

of the ***behavior***

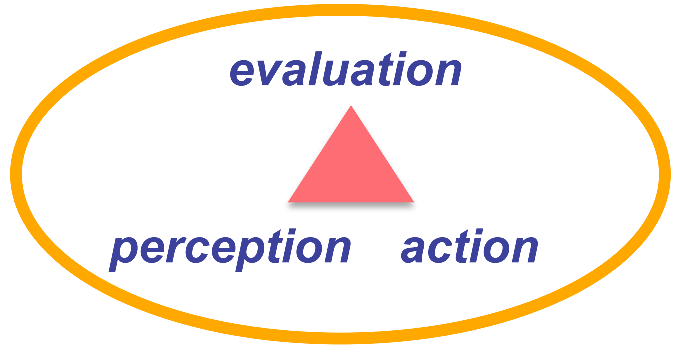
the brain organizes

in response to

perceived challenges

and opportunities.

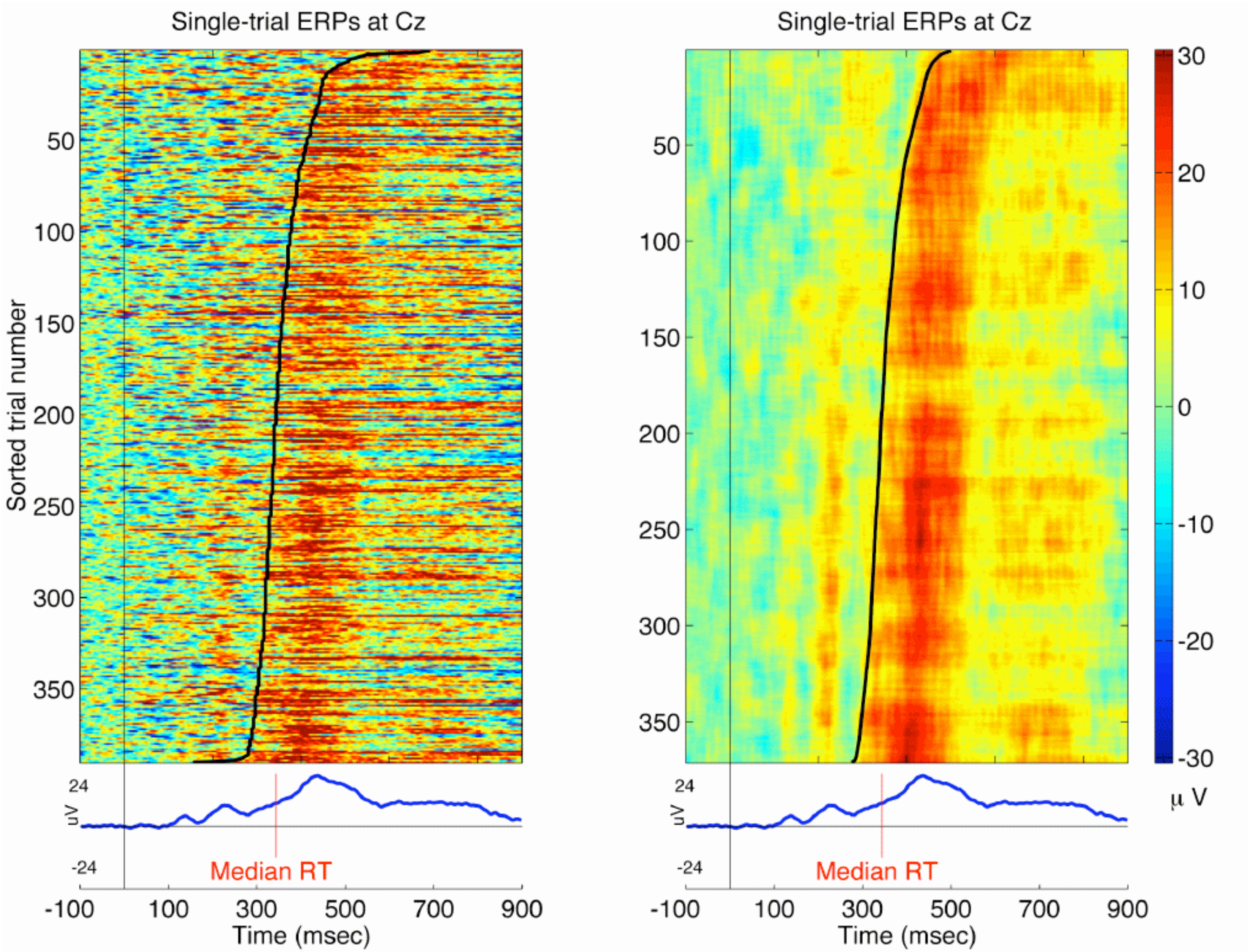
Brains meet the challenge of the moment!



S Makeig 2010

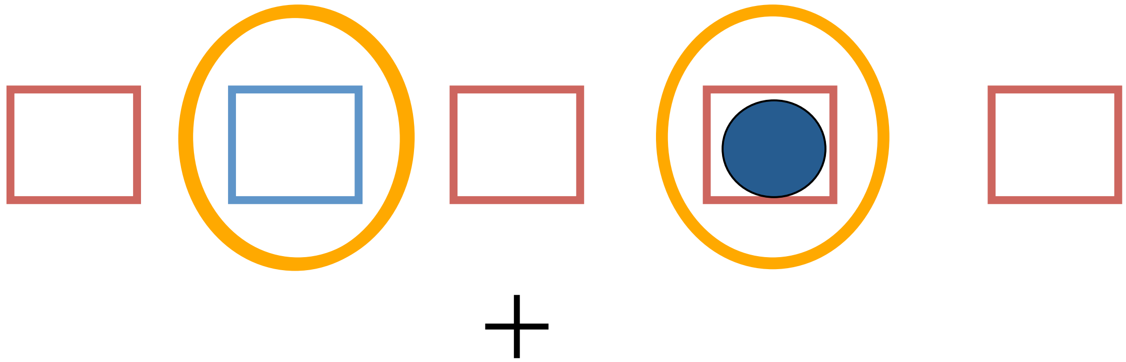
Collections of single trials, even at the source level, are regular, **but in multiple ways – so** they *appear* noisy!

Trial-to-trial Variability



Jung et al., *Human Brain Mapping*, 2001.

Visual Selective Attention Task

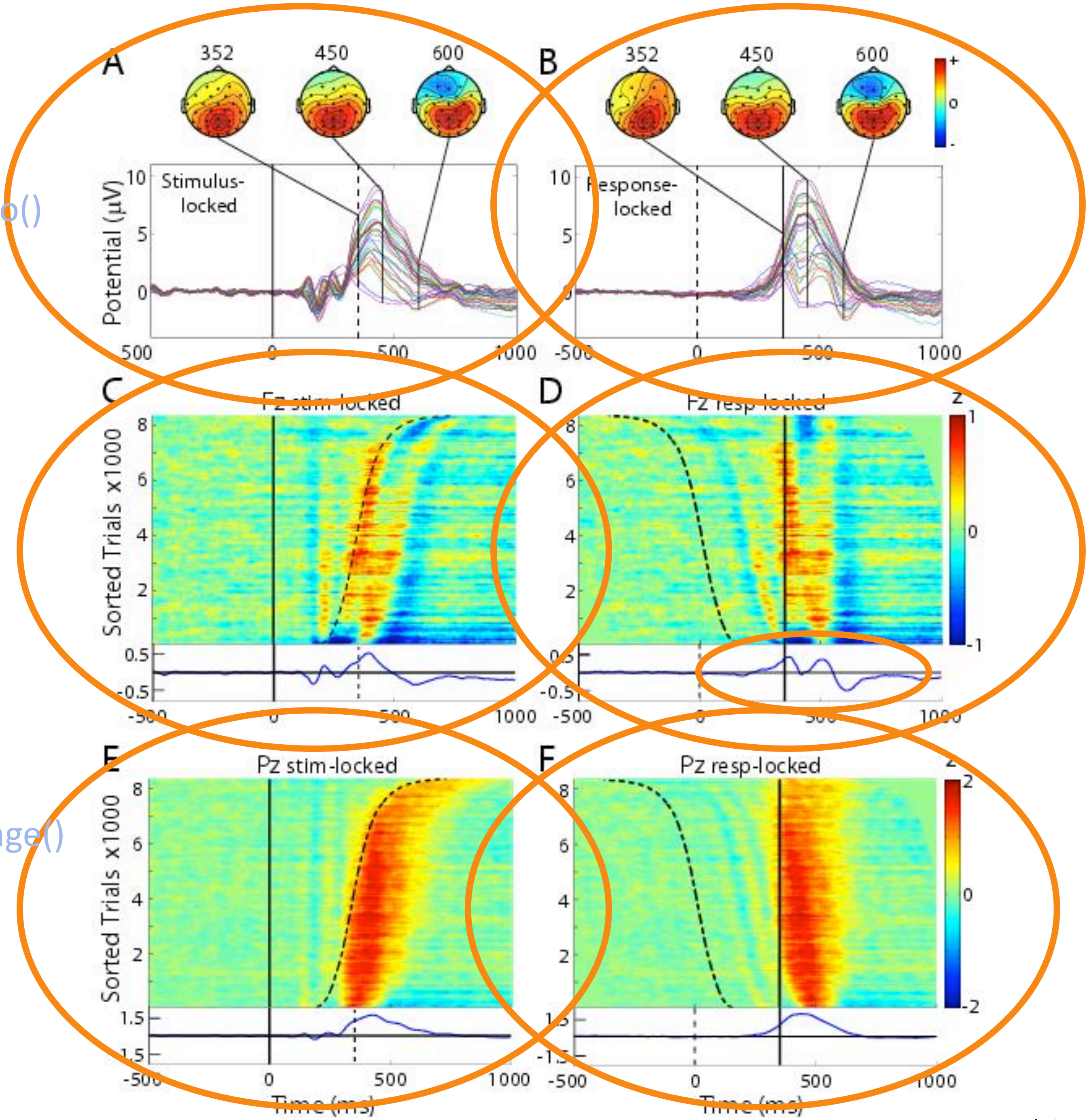


15 subjects

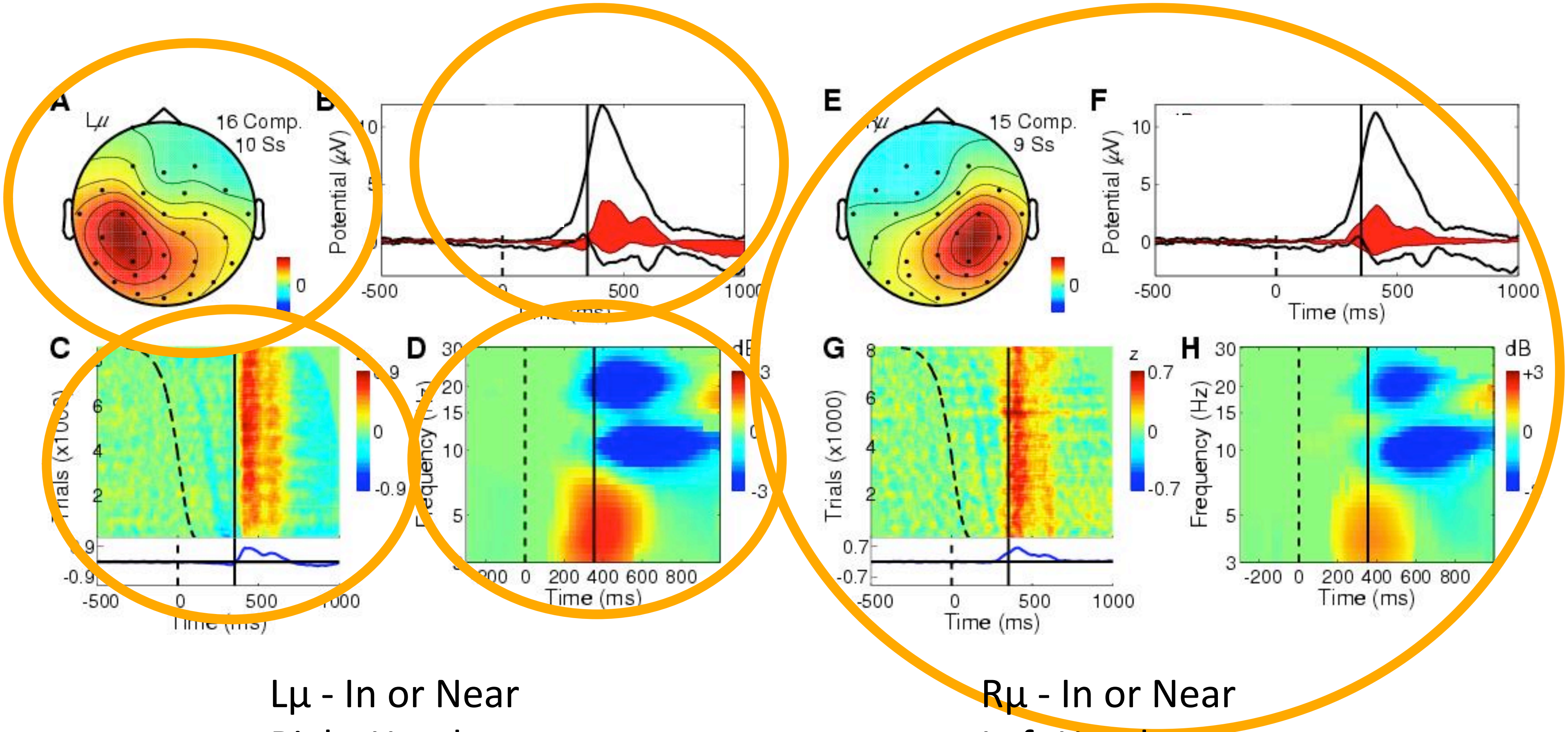
S. Makeig (2001)

timtopo()

erpimage()



S Makeig et al., *PLOS Biology* 2004



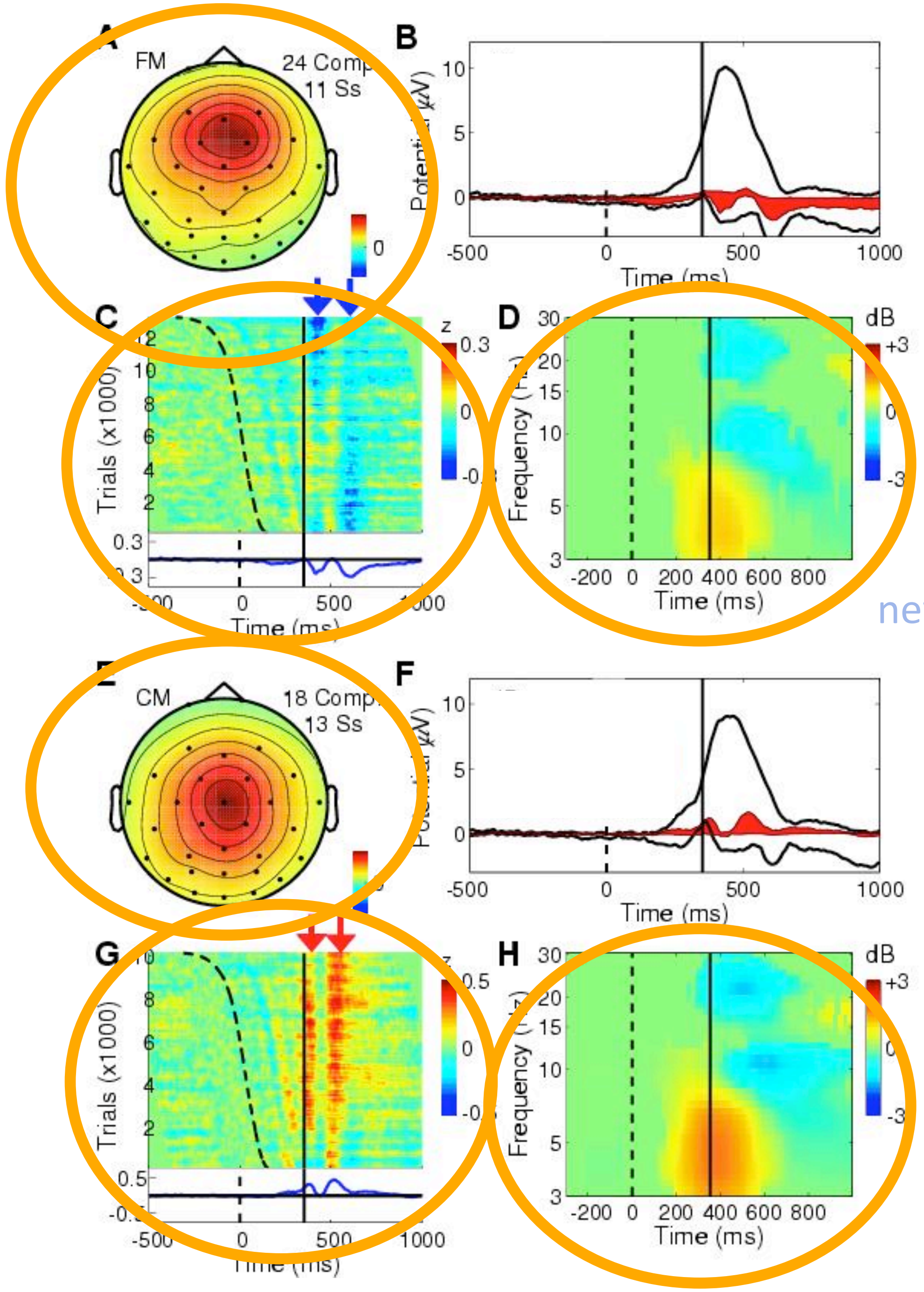
Lµ - In or Near
Right Hand
Somatomotor
Cortex

Rµ - In or Near
Left Hand
Somatomotor
Cortex

S Makeig et al., *PLOS Biology* 2004

envtopo()

std_envtopo()



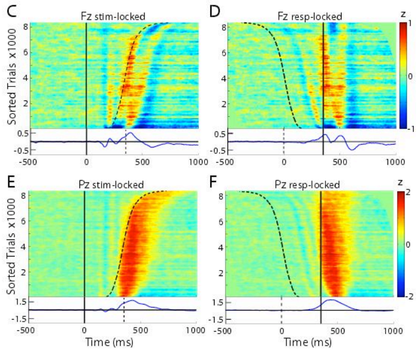
FM - In or Near Rostral Cingulate Zone (dACC)

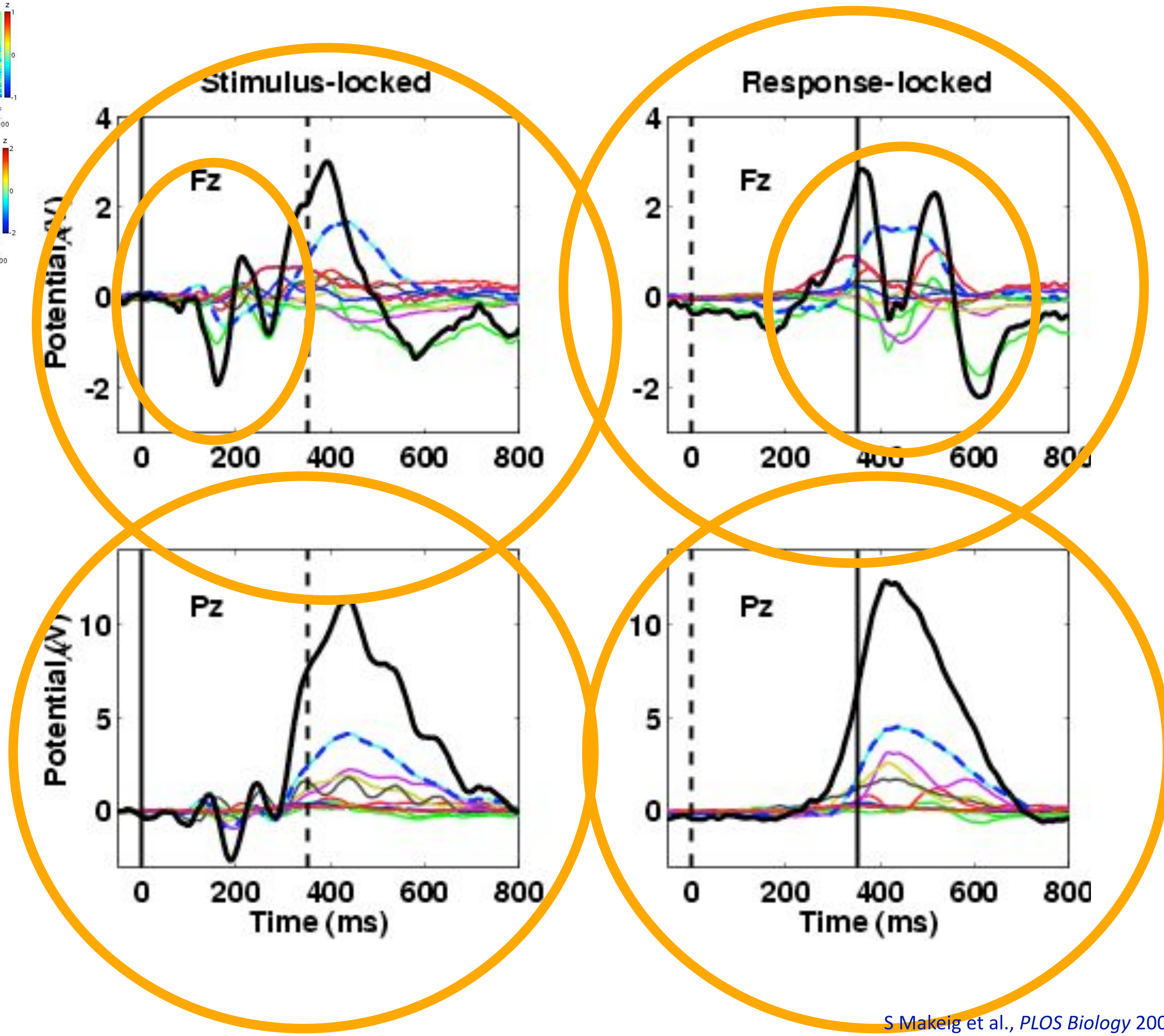
newtimef()

CM - In or Near Motor Cingulate / Supplementary Motor Cortex

S Makeig et al., *PLOS Biology* 2004

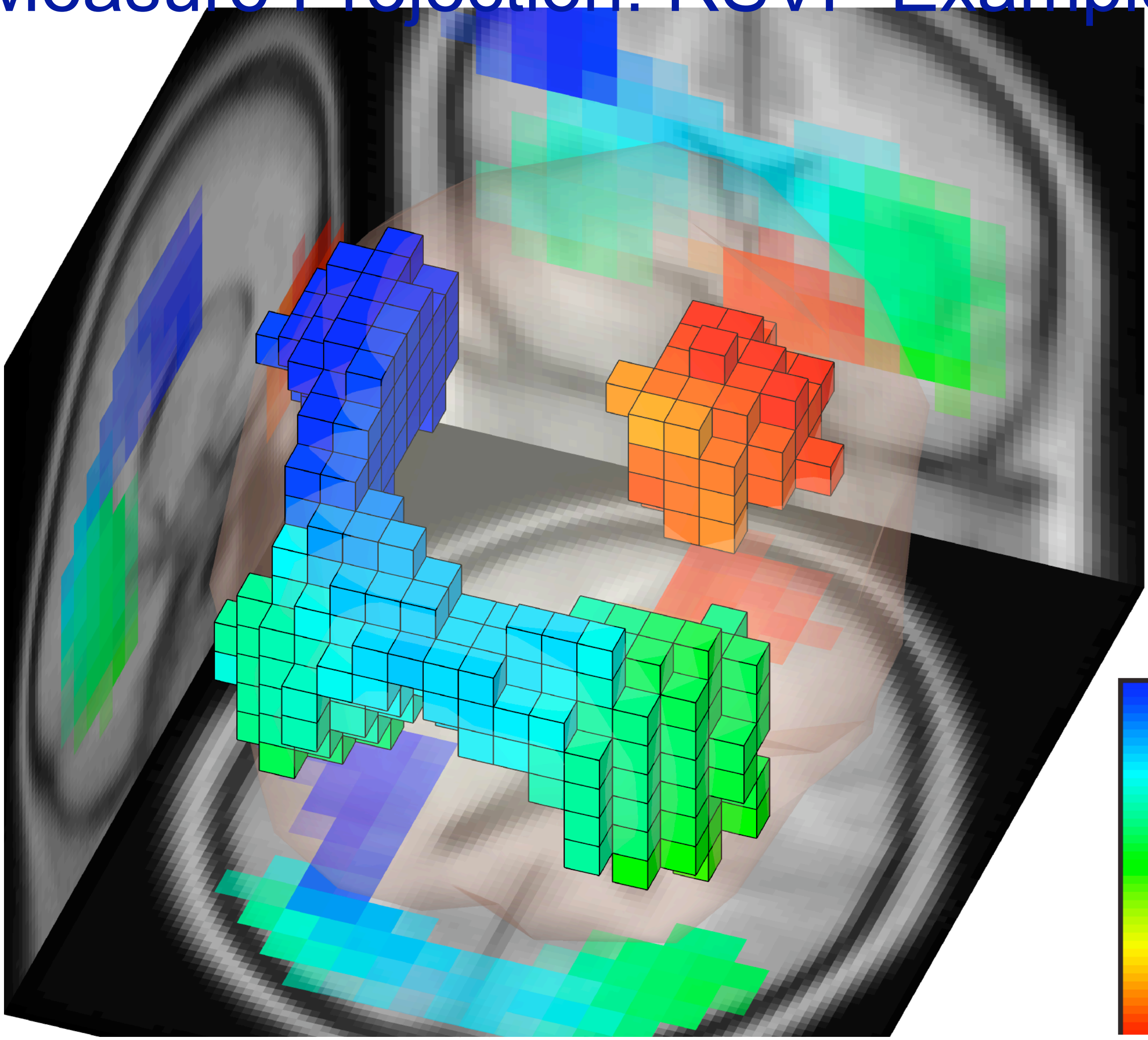
Complex event-related dynamics *sum to* ‘the’ P300





S Makeig et al., *PLOS Biology* 2004

Measure Projection: RSVP Example

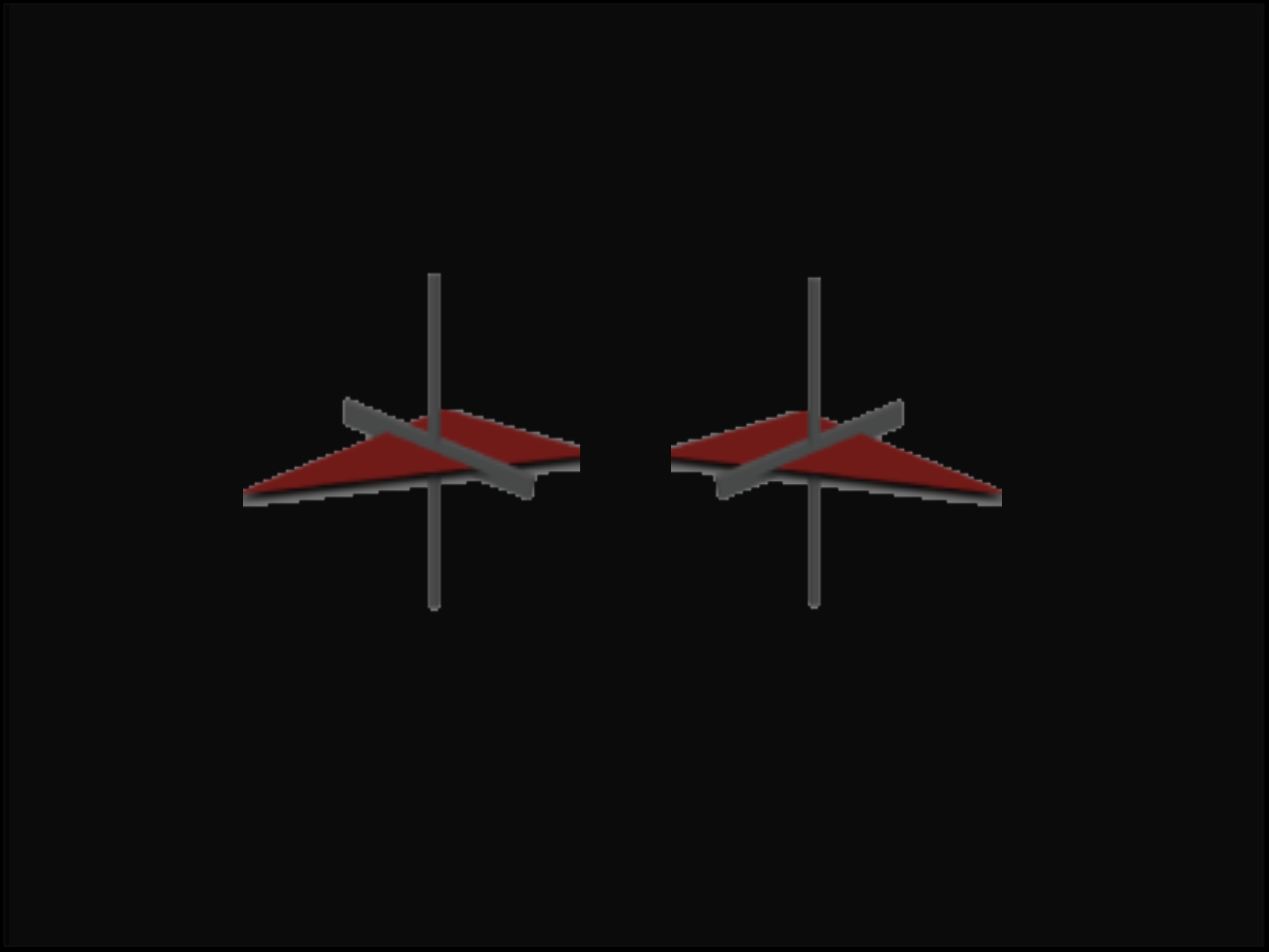


N. Bigdely-Shamlo, 2011

A Passive Spatial Navigation Paradigm

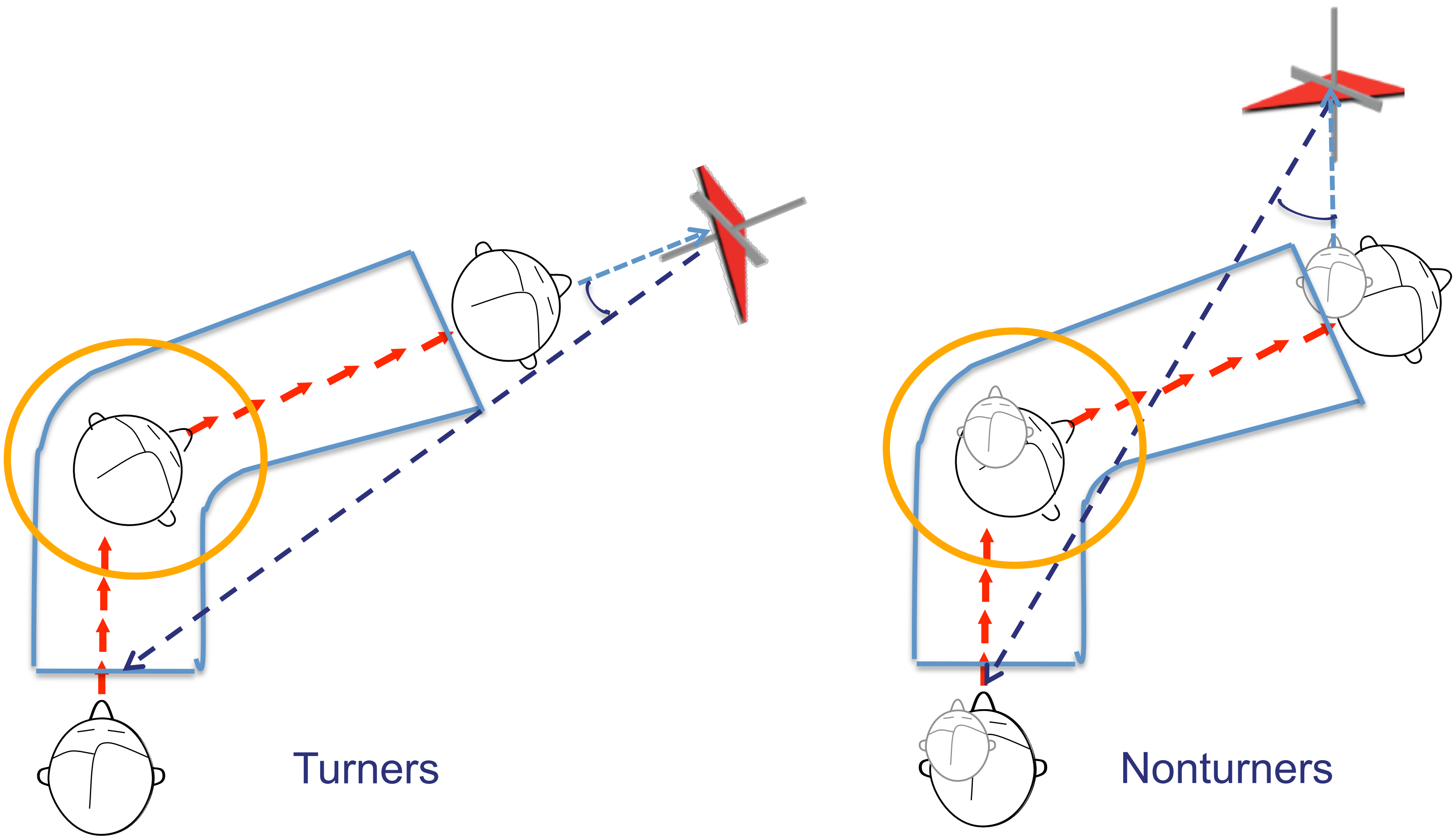
Klaus Gramann et al., 2010

A Passive Spatial Navigation Paradigm



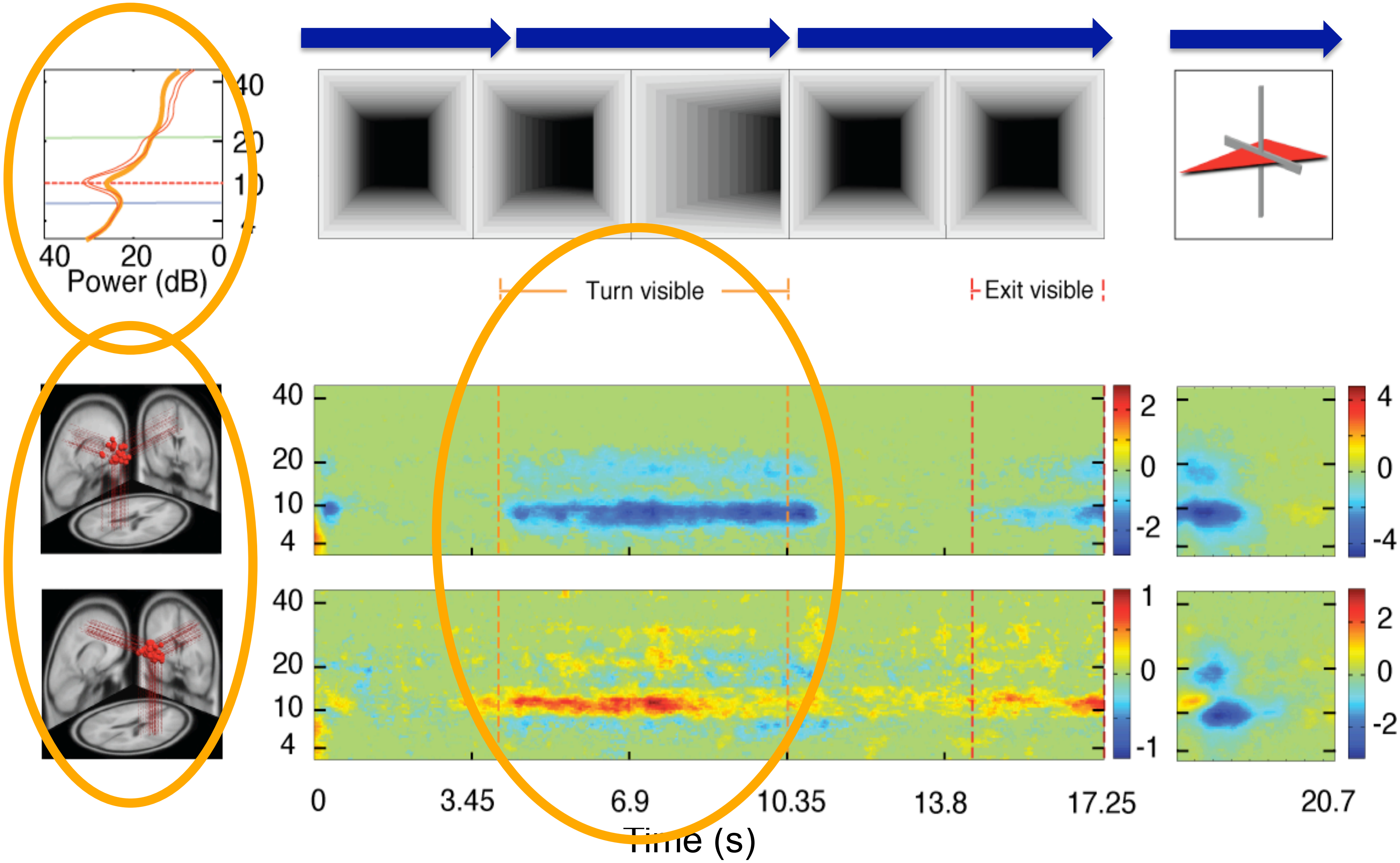
Klaus Gramann et al., 2010

‘Turner’ and ‘Nonturner’ subjects use different spatial orienting styles



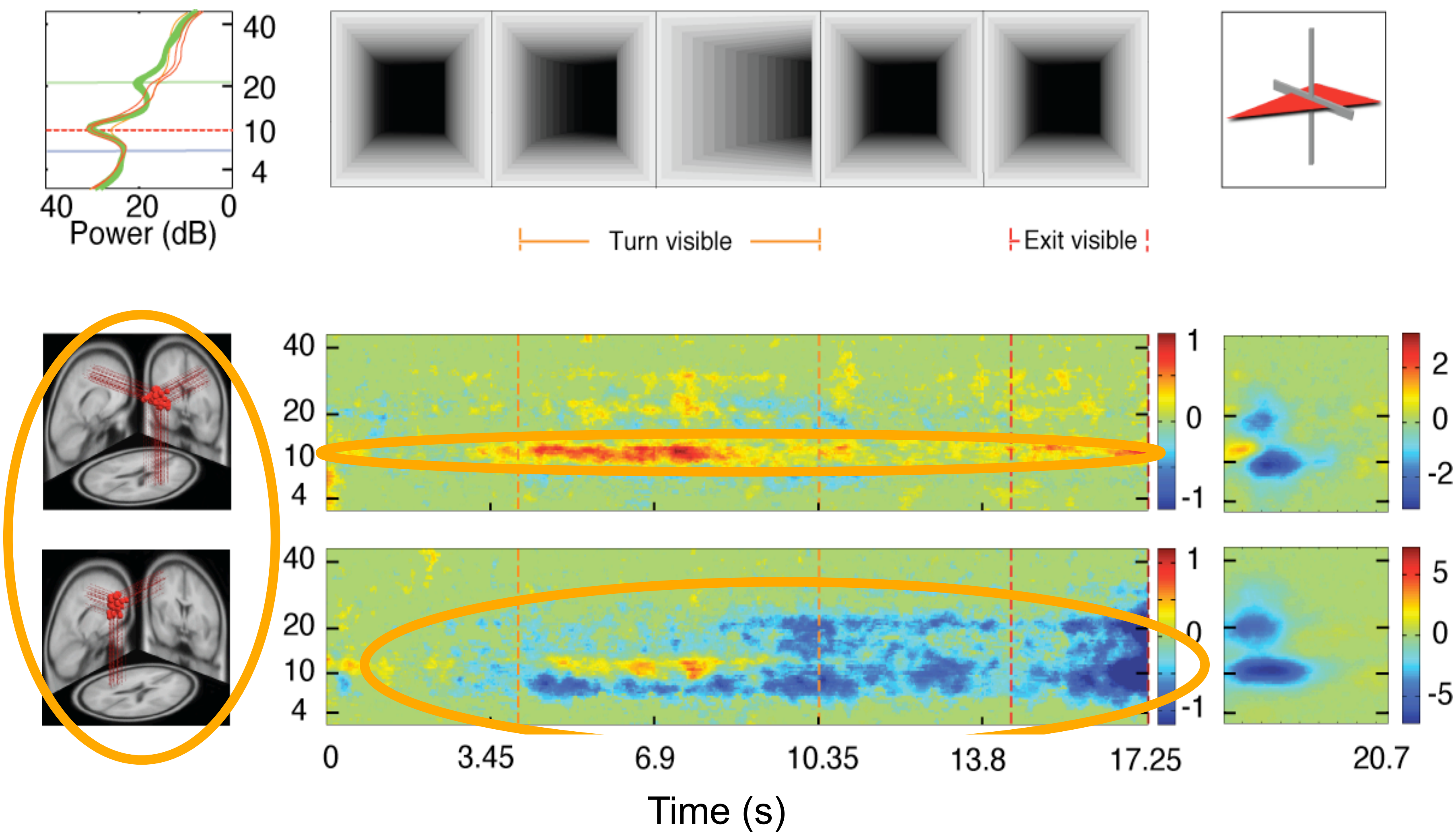
Klaus Gramann & S. Makeig, 2010

Parietal component clusters



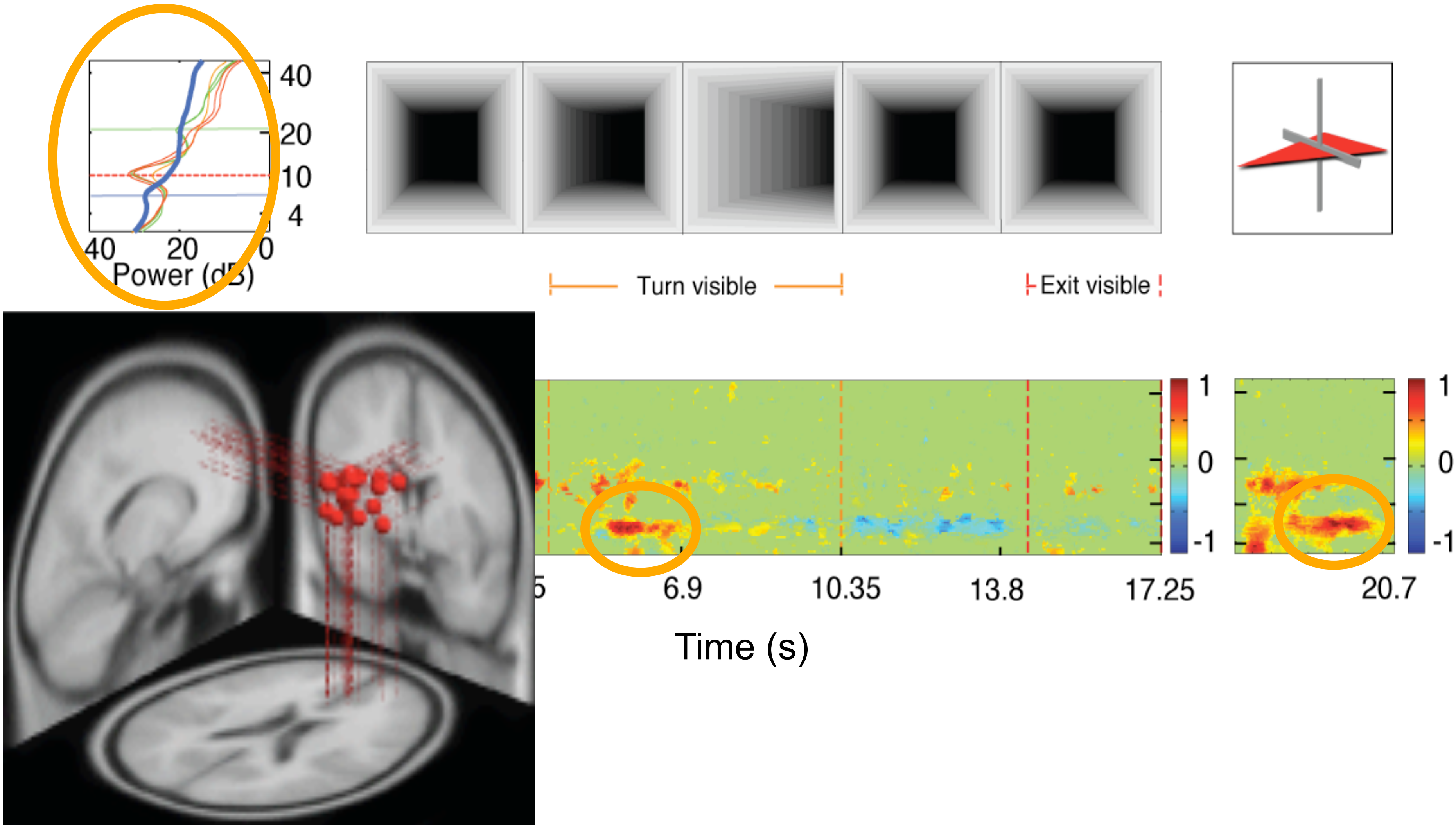
Klaus Gramann et al., 2010

Pre-motor component clusters



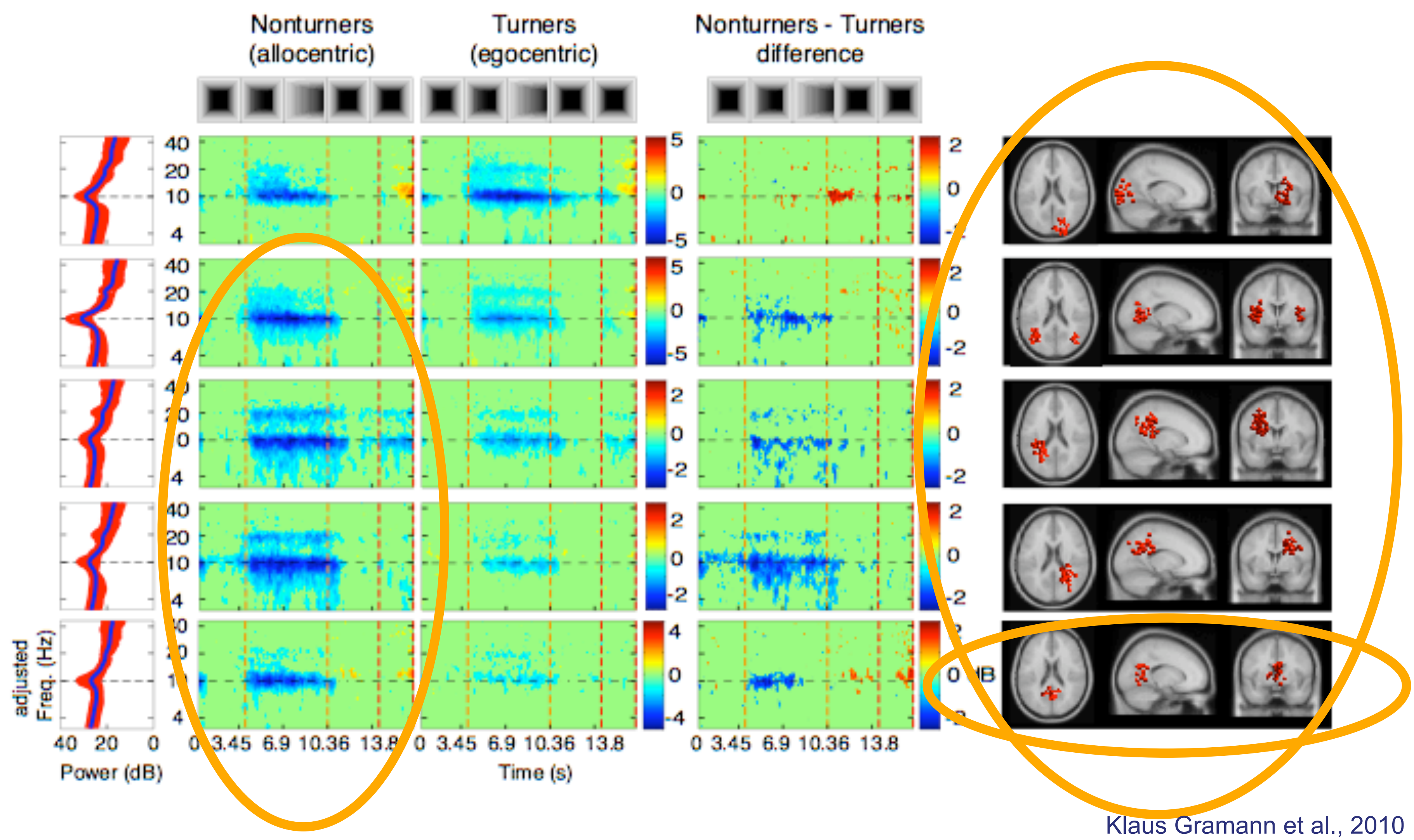
Klaus Gramann et al., 2010

Medial prefrontal component clusters



Klaus Gramann et al., 2010

Clusters distinguishing Turners & Nonturners



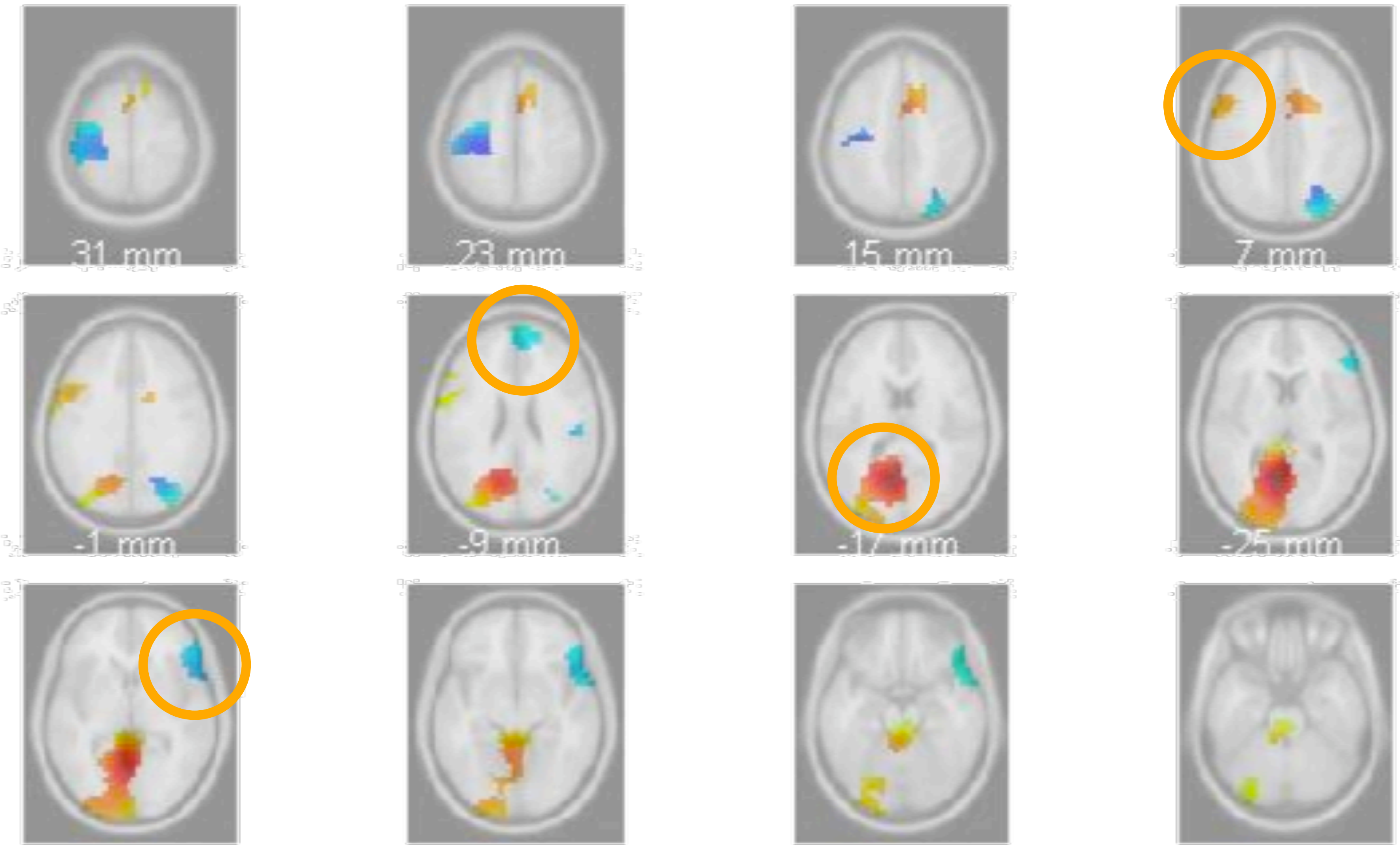
Klaus Gramann et al., 2010

Visual spatial working memory in young and older adults

EEG & Aging

V. Bjerre J. Onton, & S. Makeig, 2006

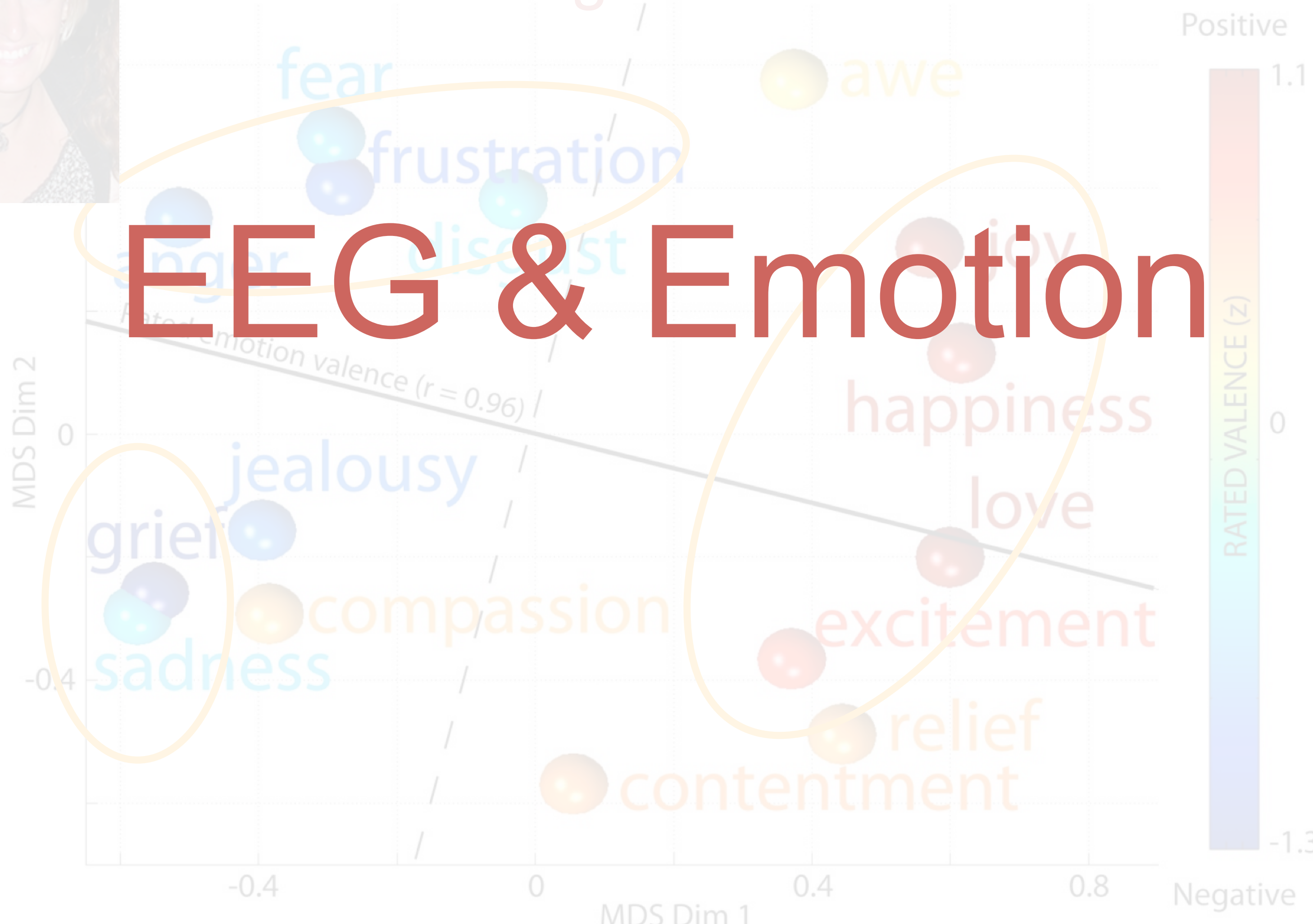
Young adults – Older adults



V. Bjerre J. Onton, & S. Makeig, 2006

EEG & Emotion

Changes in distribution of broadband high-frequency EEG power with imagined emotion



Julie Onton & Scott Makeig, *Frontiers in Human Neuroscience*, 2009

JUST: A quartet suite for flute, violin, cello, and brain

Fourth International BCI Meeting
Asilomar Meeting Grounds, Pacific Grove, CA
June, 2010

Mobile Brain/body Imaging (MoBI)

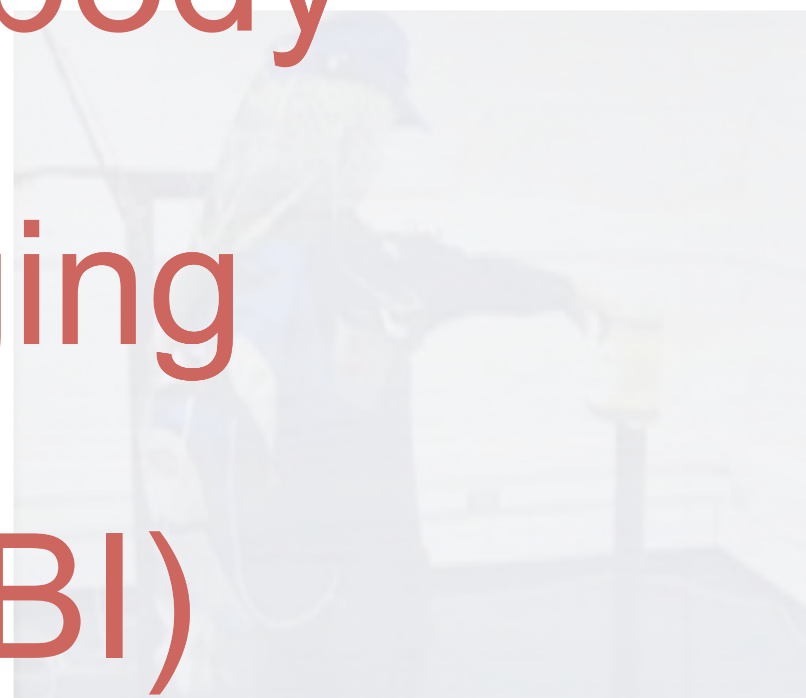
Brain imaging during movement – How?

- Current advances in miniaturization, computer power, and information-based signal processing make possible a new imaging modality:

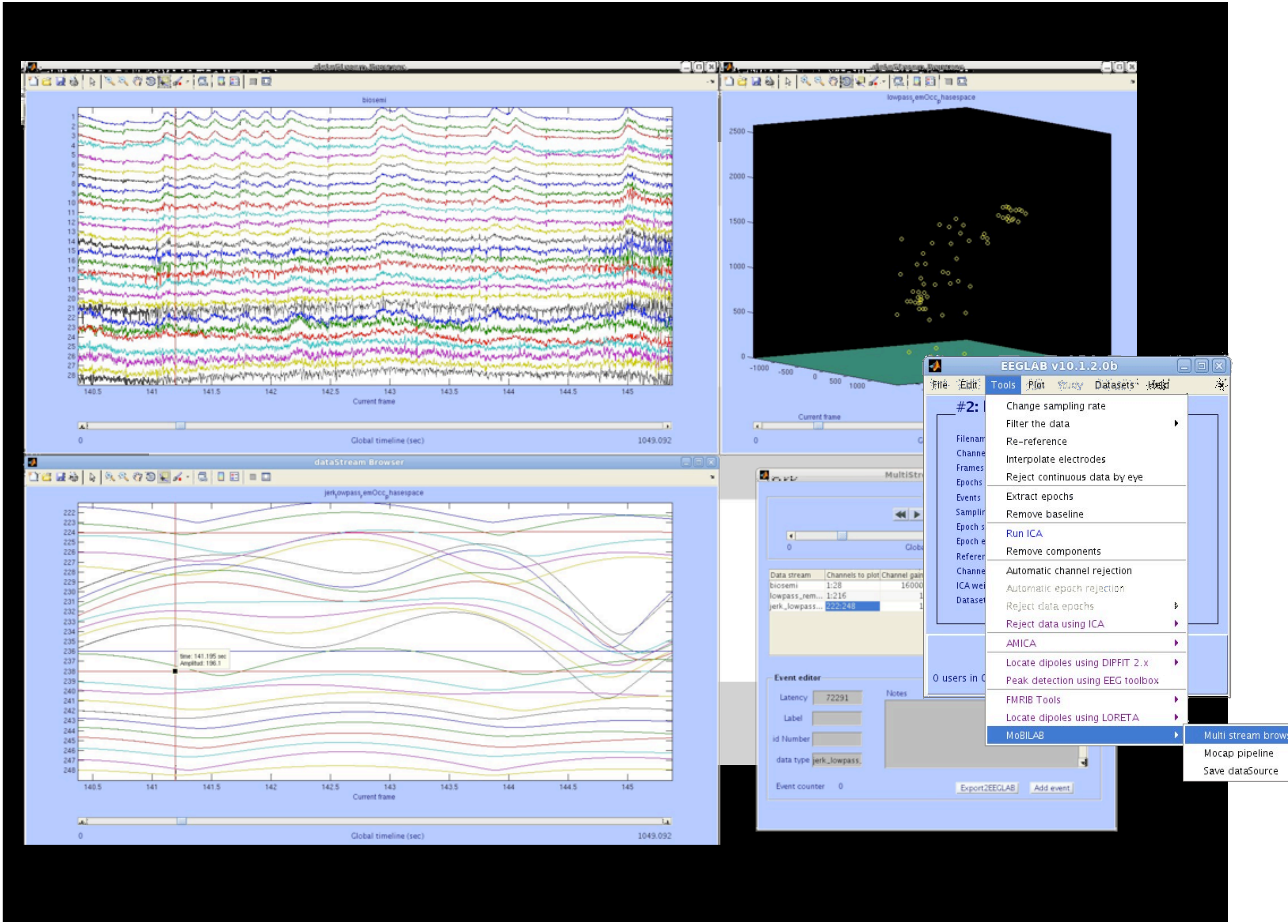
→ **Mobile Brain/Body Imaging** (MoBI)

Concept:

Combine whole-head EEG, eye gaze tracking, and whole-body motion capture recording in a real-world 3-D environment.

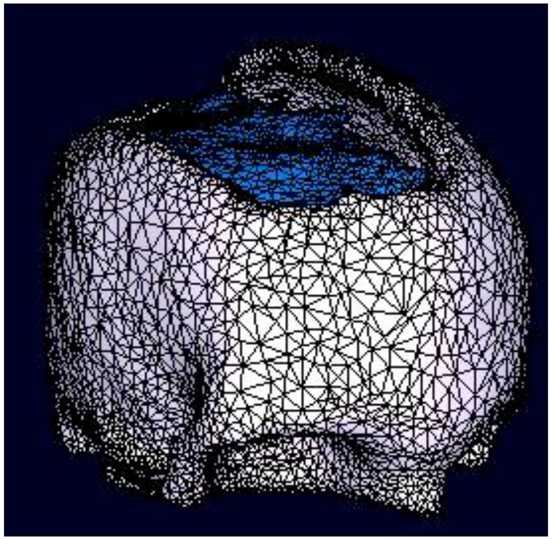


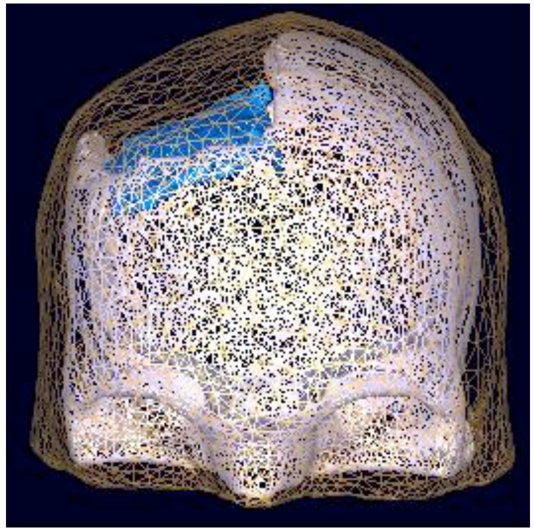
Scott Makeig, 2008

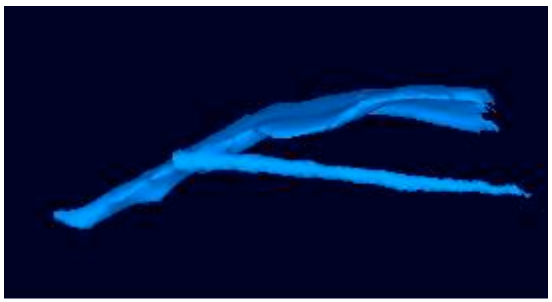

biosemi
Current frame
Global timeline (sec)
1049.092
lowpass_emOcc_hasespace
Current frame
dataStream Browser
jerk_lowpass_emOcc_hasespace
Current frame
Global timeline (sec)
1049.092
EEGLAB v10.1.2.0b
File
Edit
Tools
Plot
Study
Datasets
Help
#2:
Change sampling rate
Filter the data
Re-reference
Interpolate electrodes
Reject continuous data by eye
Extract epochs
Remove baseline
Run ICA
Remove components
Automatic channel rejection
Automatic epoch rejection
Reject data epochs
Reject data using ICA
AMICA
Locate dipoles using DIPFIT 2.x
Peak detection using EEG toolbox
FMRIB Tools
Locate dipoles using LORETA
MoBILAB
Multi stream browse
Mocap pipeline
Save dataSource
0 users in
Data stream
Channels to plot
Channel gain
biosemi
1:28
16000
lowpass_rem...
1:216
jerk_lowpass...
222:248
Event editor
Latency
72291
Label
id Number
data type
jerk_lowpass
Notes
Event counter
0
Export2EEGLAB
Add event

Finding EcoG Sources

(invasive monitoring before surgery for epilepsy)



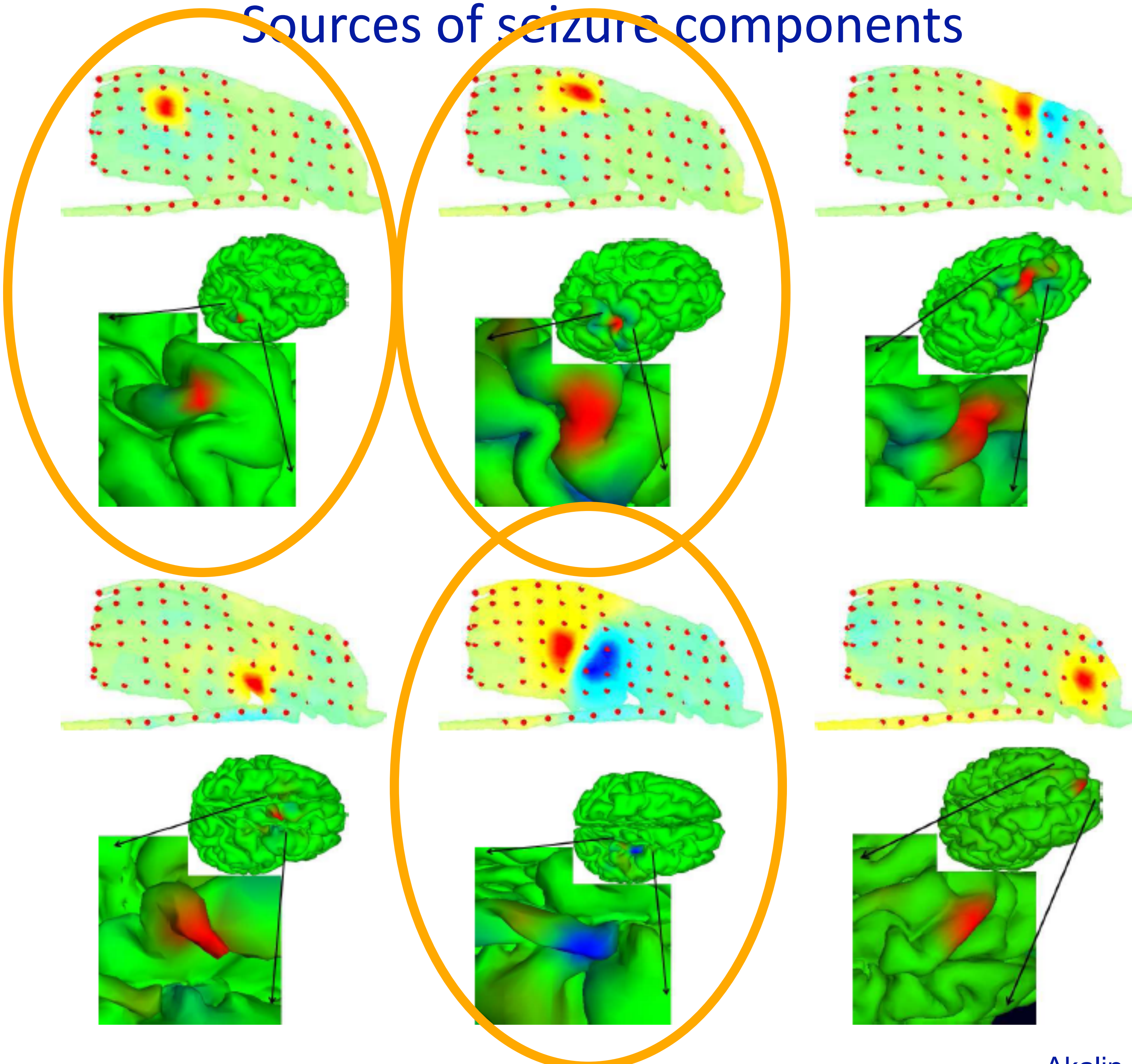




Number of elements:
Scalp: 10,000
Skull: 30,000
Plastic sheet : 7,000

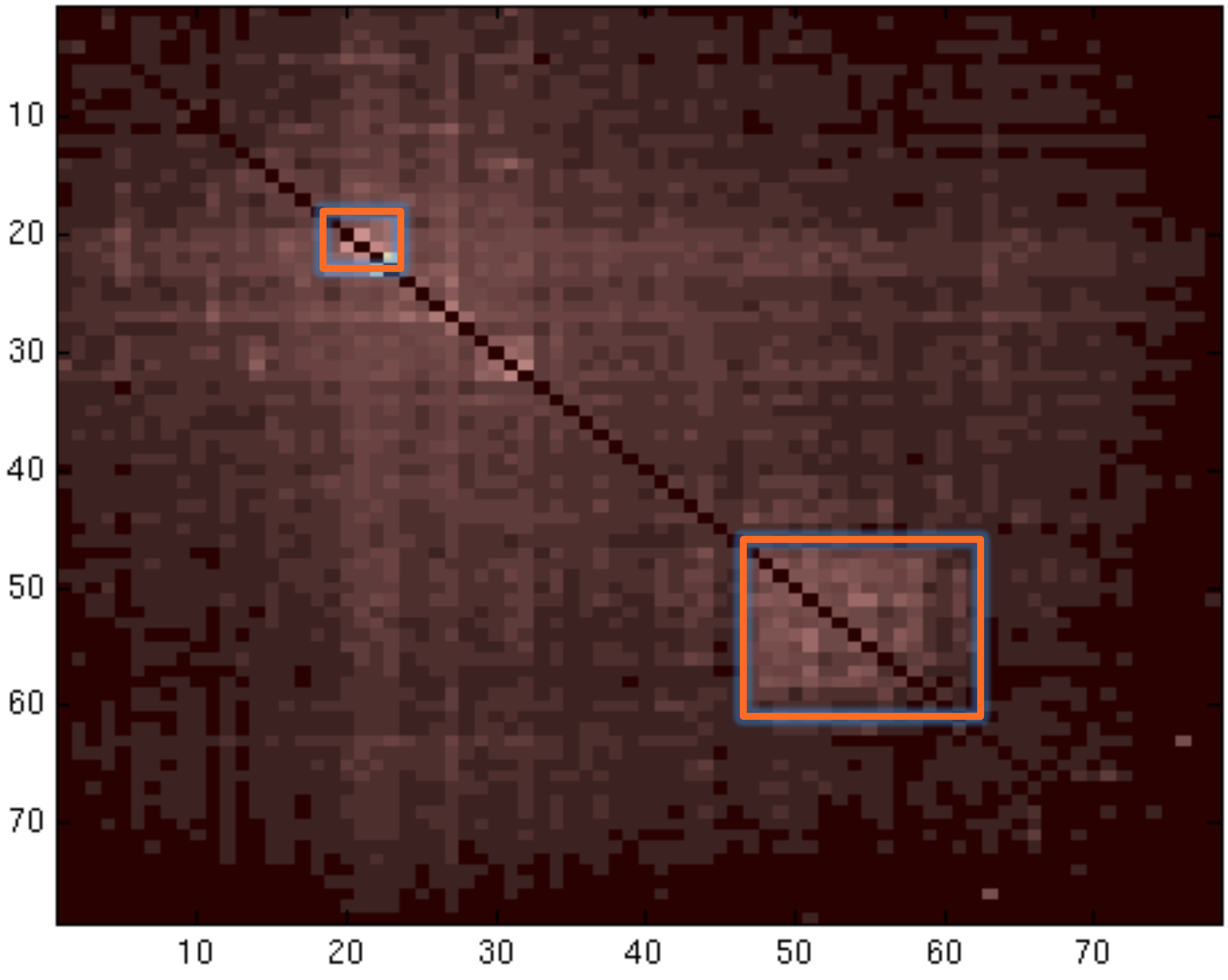
Akalin Acar et al. 2011

Sources of seizure components

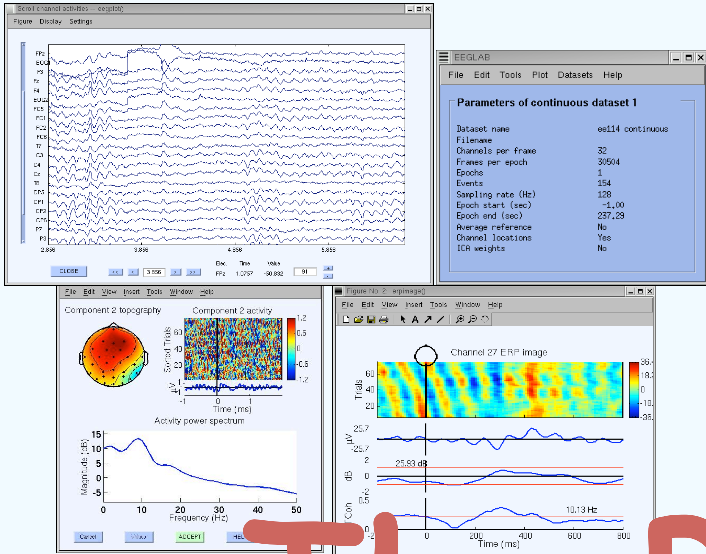


Akalin Acar et al. 2011

5-model AMICA decomposition (dependent subspaces)



Akalin Acar et al. 2011



The Beginning

fEEG, BMI, …