ICA for Artifact Removal: Why and how …

Scott Makeig

Institute for Neural Computation

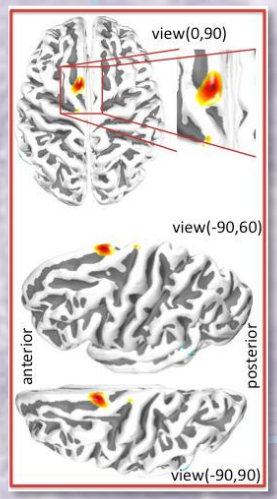
University of California San Diego

OHBM 2020 Online Course on EEG pre-processing

recorded

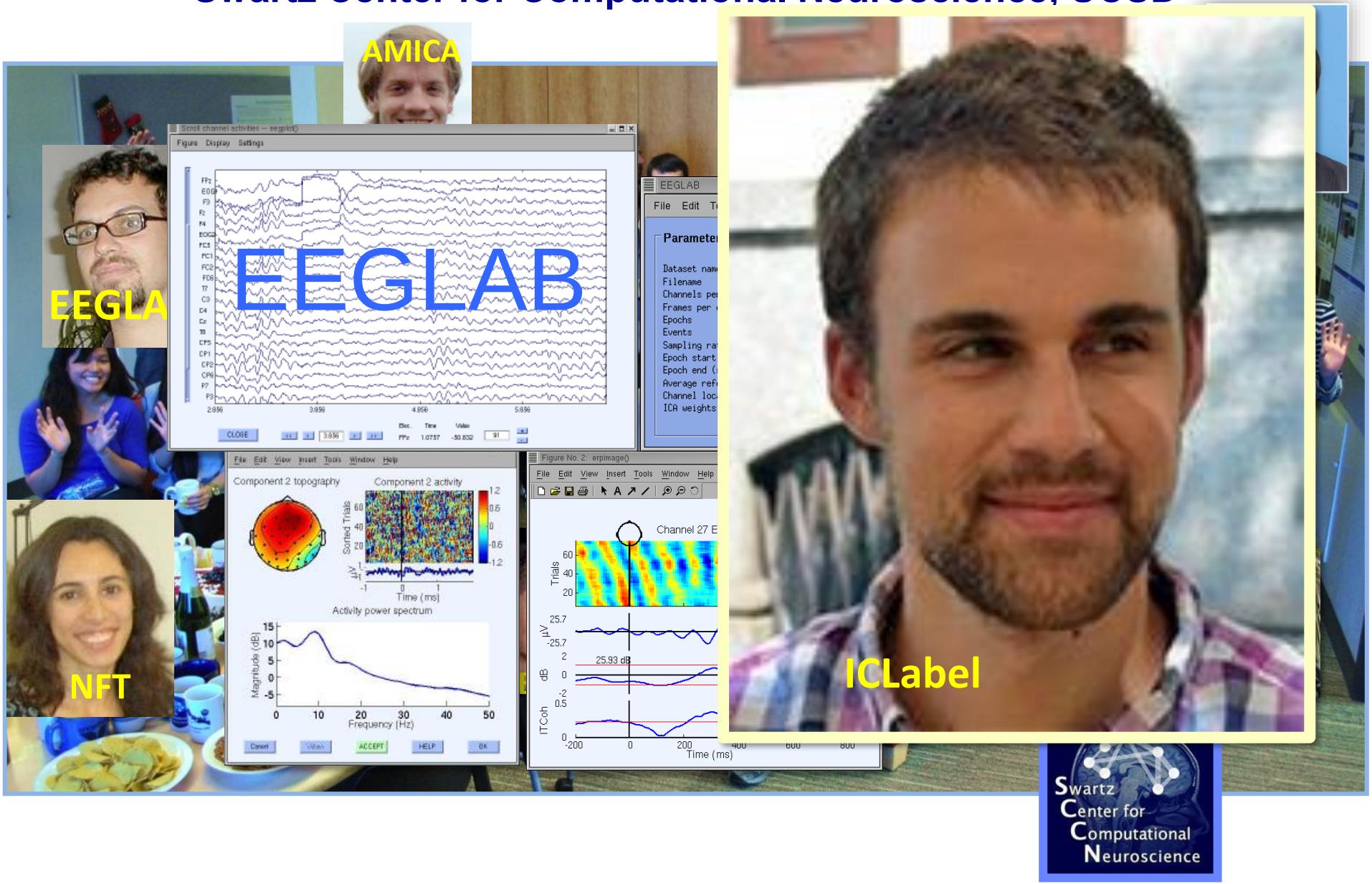
Asheville NC

June 5, 2020



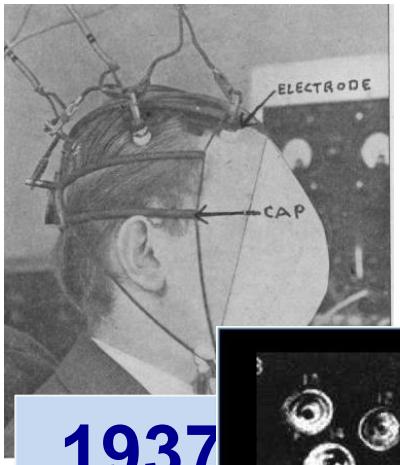
smakeig@ucsd.edu, 2018

Swartz Center for Computational Neuroscience, UCSD

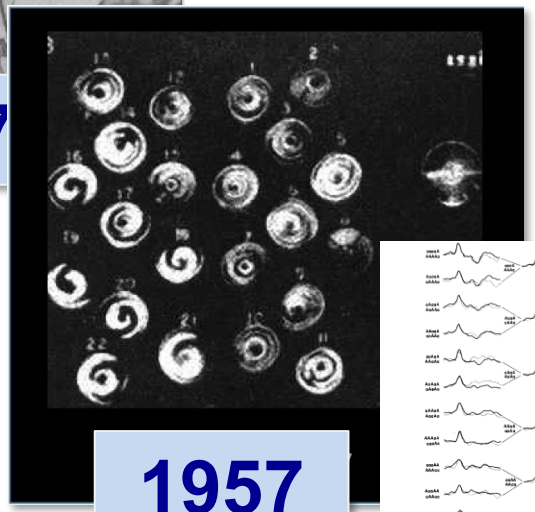


10th Anniversary SCCN Impromptu celebration 1/2/12

Development of EEG brain Imaging …

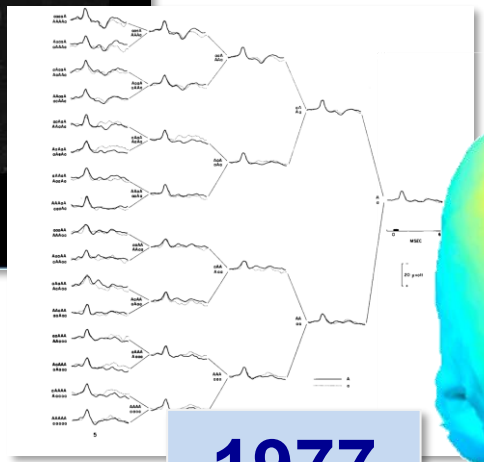


1937



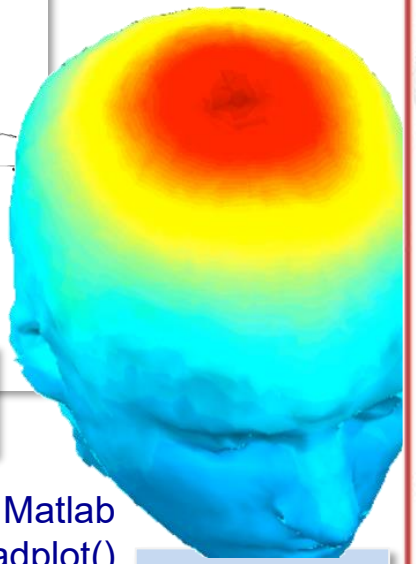
1957

Toposcope
Grey Walter



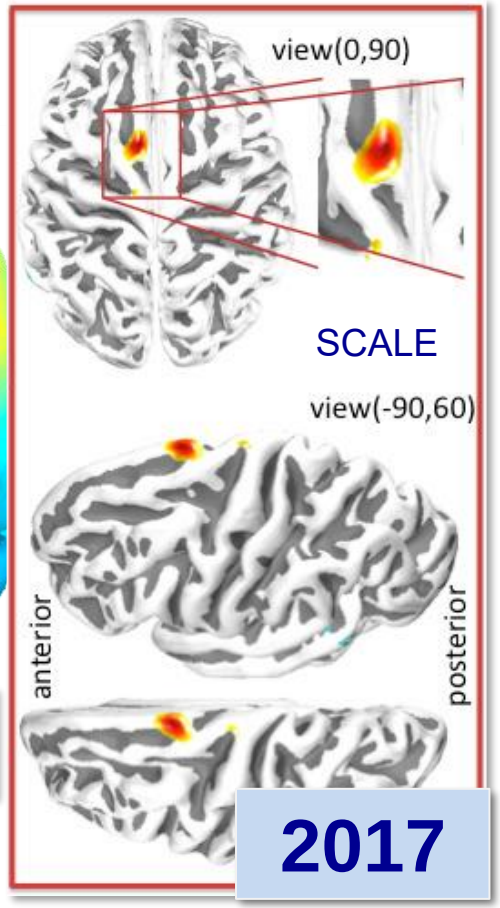
Oddball ERPs
K. Squires et al.

1977



Matlab
headplot()
→ EEGLAB

1997



2017

Z. Akalin Acar et al.

What is scalp EEG?

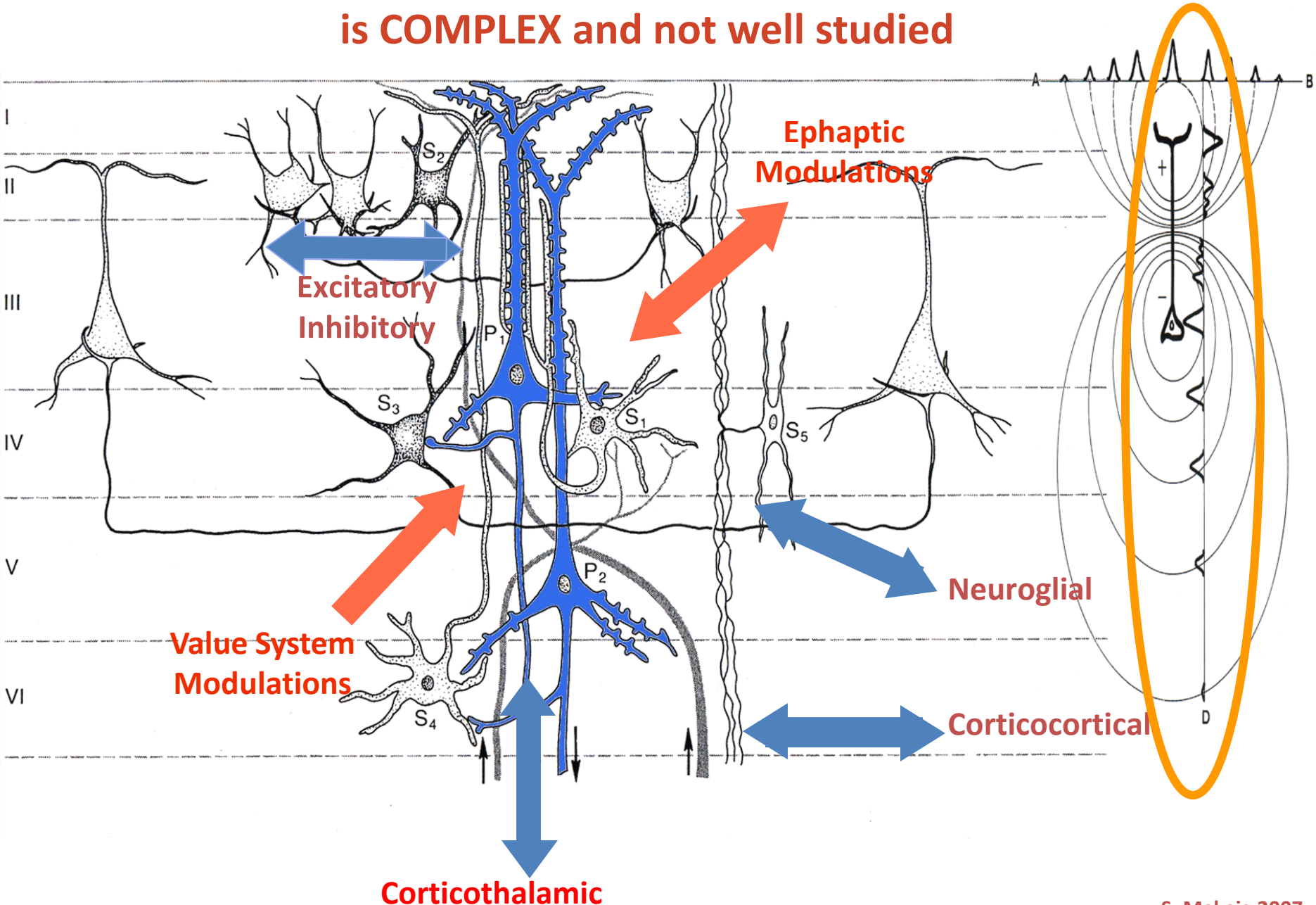
- A small portion of *cortical* electrical activity
- An even smaller portion of *total* brain electrical activity

- **But *which* portion?**
- **Triggered and modulated *how*?**
- **With *what* functional significance?**

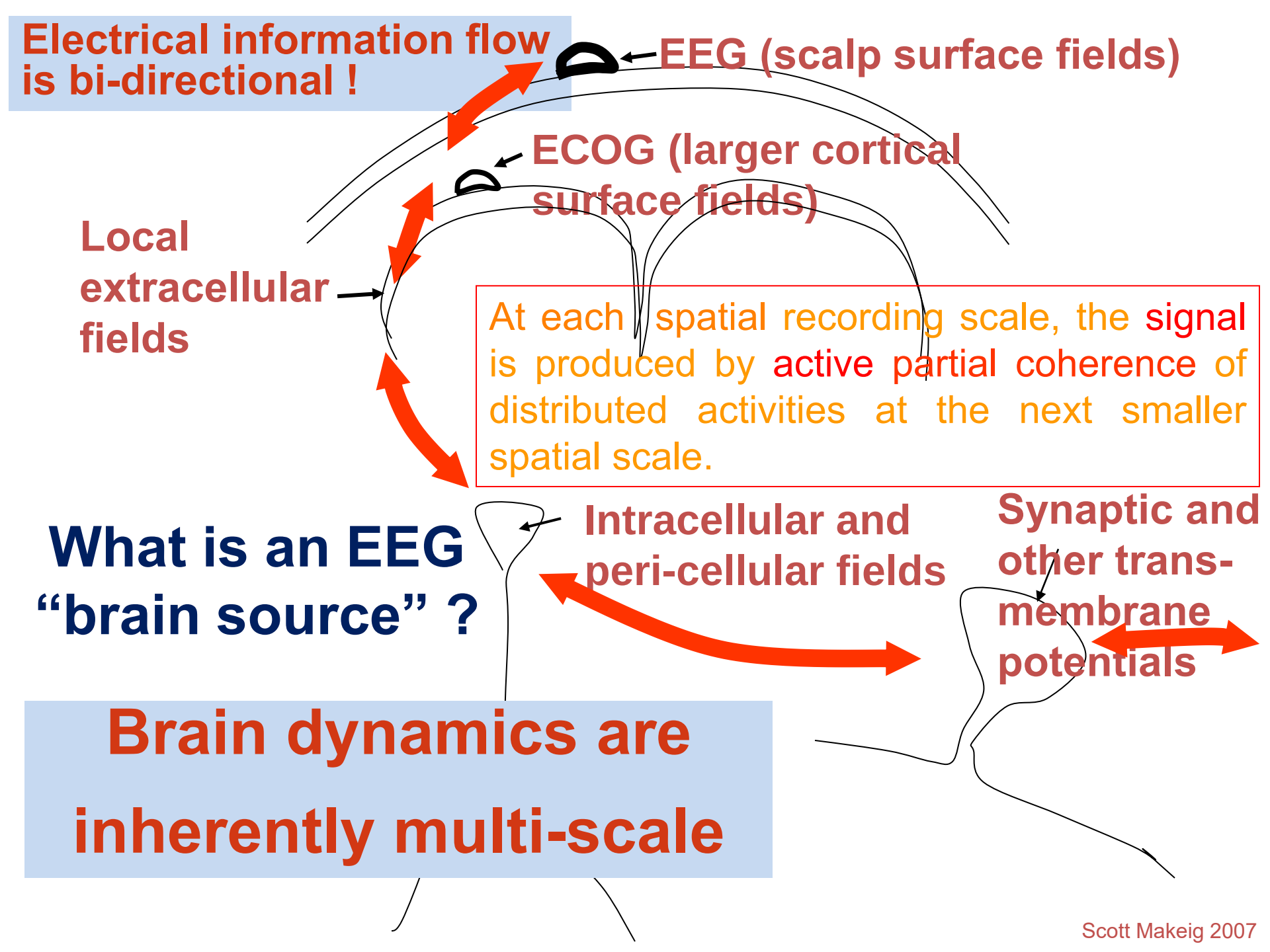
Cloud art: Berndnaut Smilde

S. Makeig, 2016

The generation and modulation of local field potentials is COMPLEX and not well studied

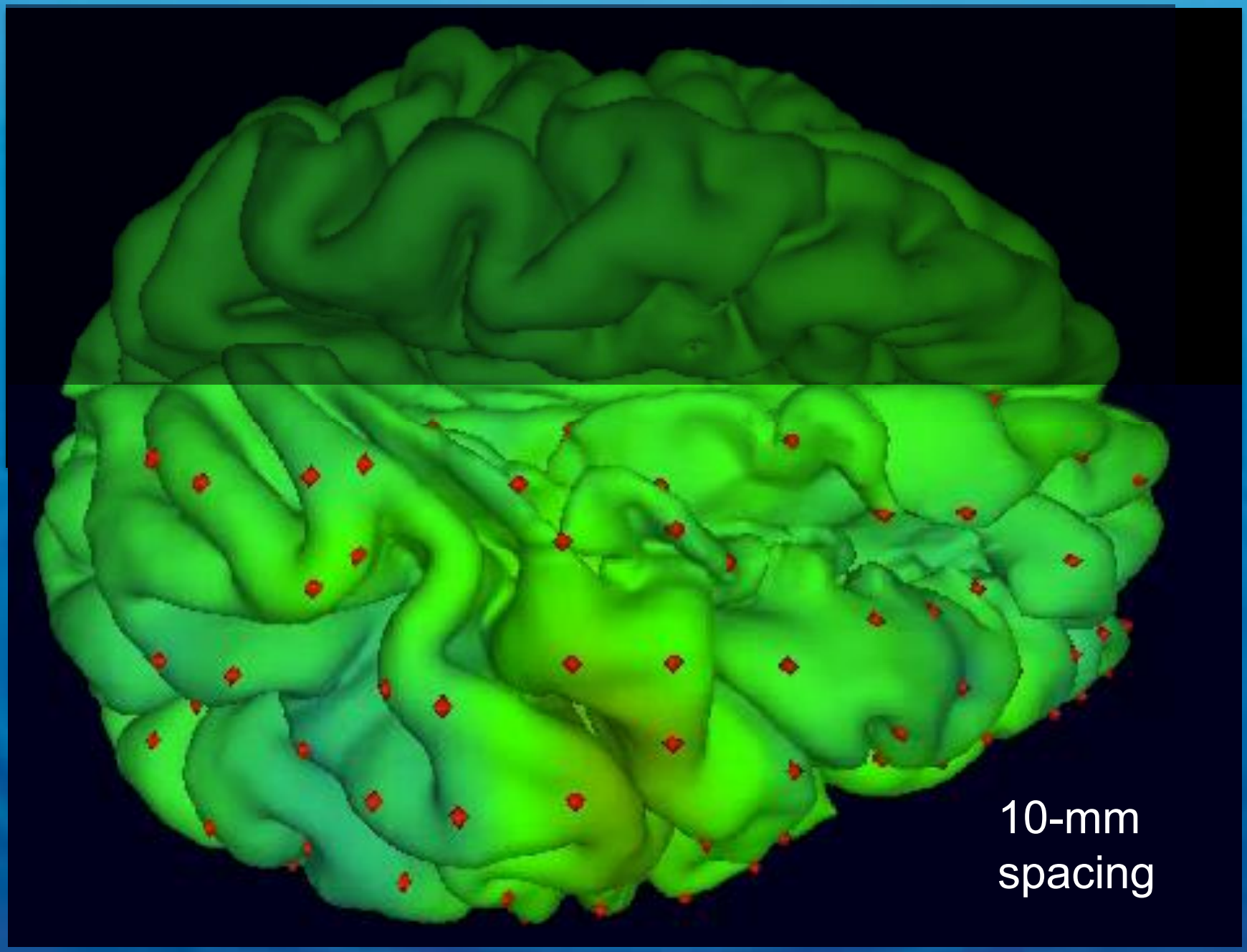


S. Makeig 2007


Electrical information flow is bi-directional !
EEG (scalp surface fields)
ECOG (larger cortical surface fields)
Local extracellular fields
At each spatial recording scale, the signal is produced by active partial coherence of distributed activities at the next smaller spatial scale.
What is an EEG "brain source" ?
Intracellular and peri-cellular fields
Synaptic and other trans-membrane potentials
Brain dynamics are inherently multi-scale
Scott Makeig 2007

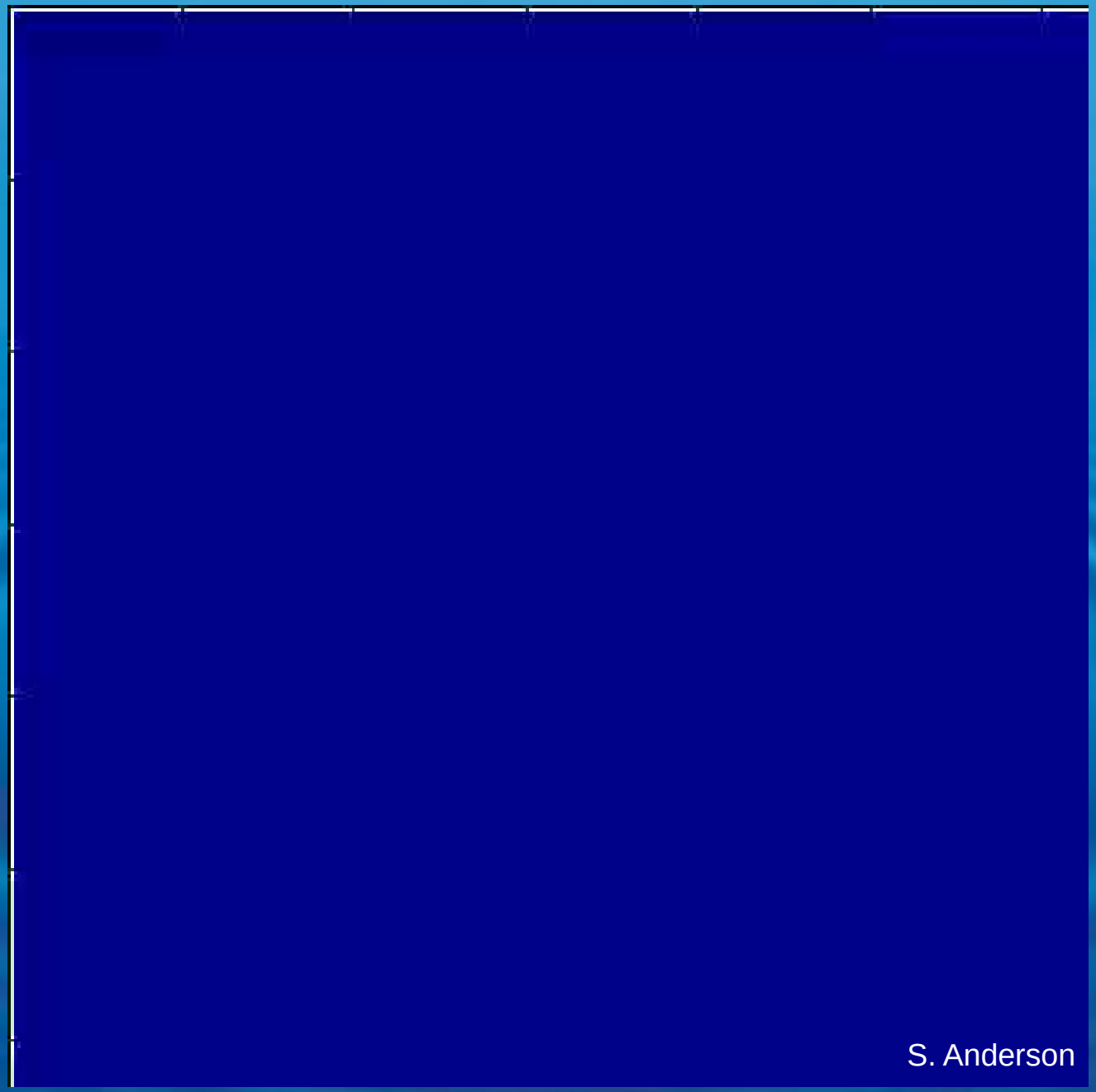
The spatiotemporal dynamics of cortex & brain have not yet been imaged on multiple spatial scales!

Alan Friedman



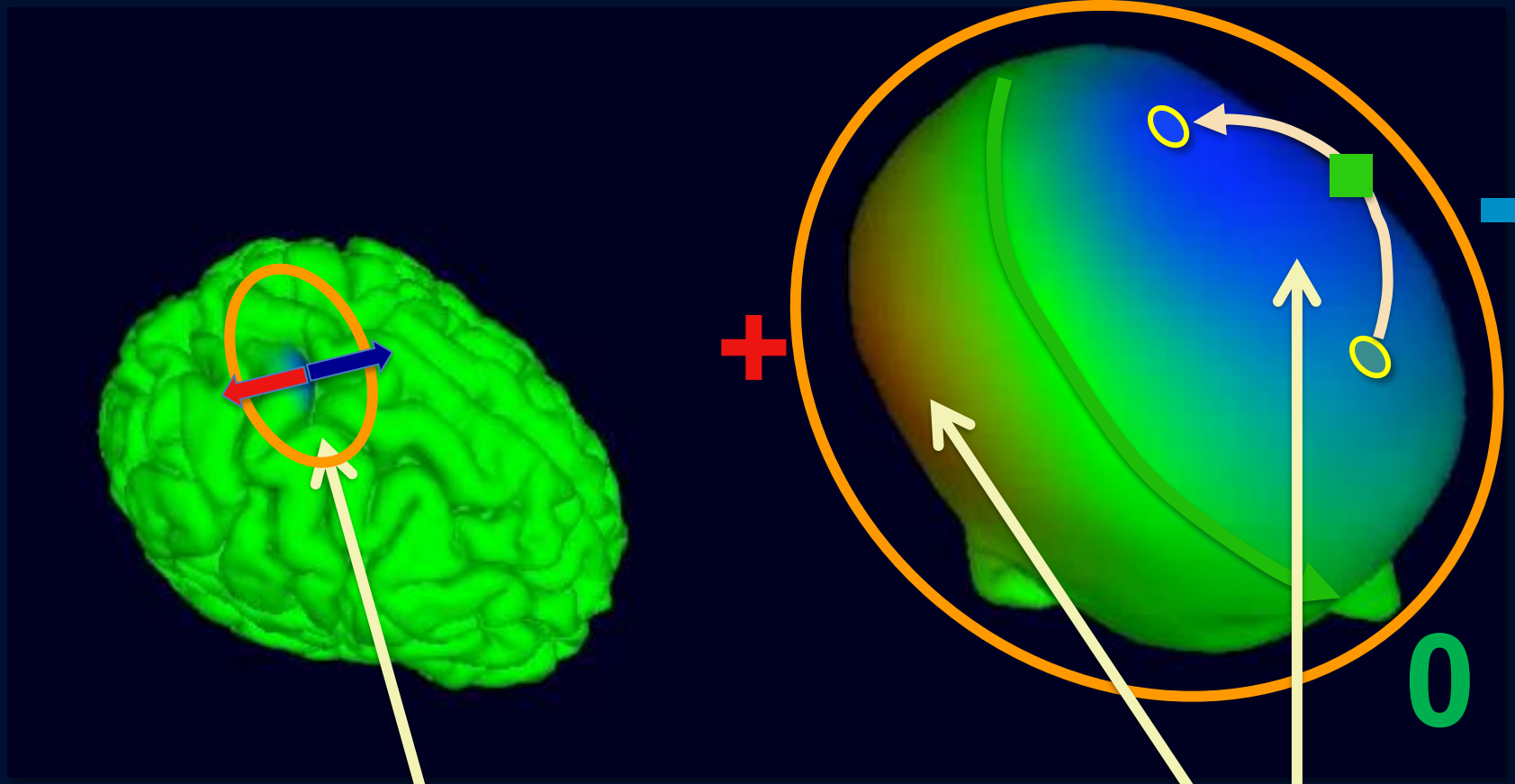
Z Akalin Acar, 2017

Phase cones (Freeman)



RS Anderson, 2007

The very broad EEG point-spread function

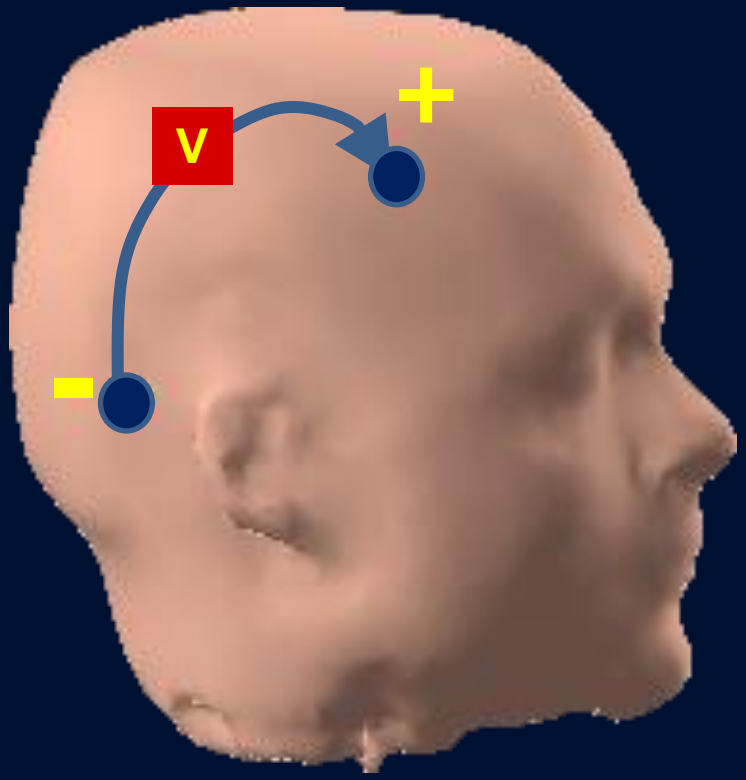


Single simulated parietal source →

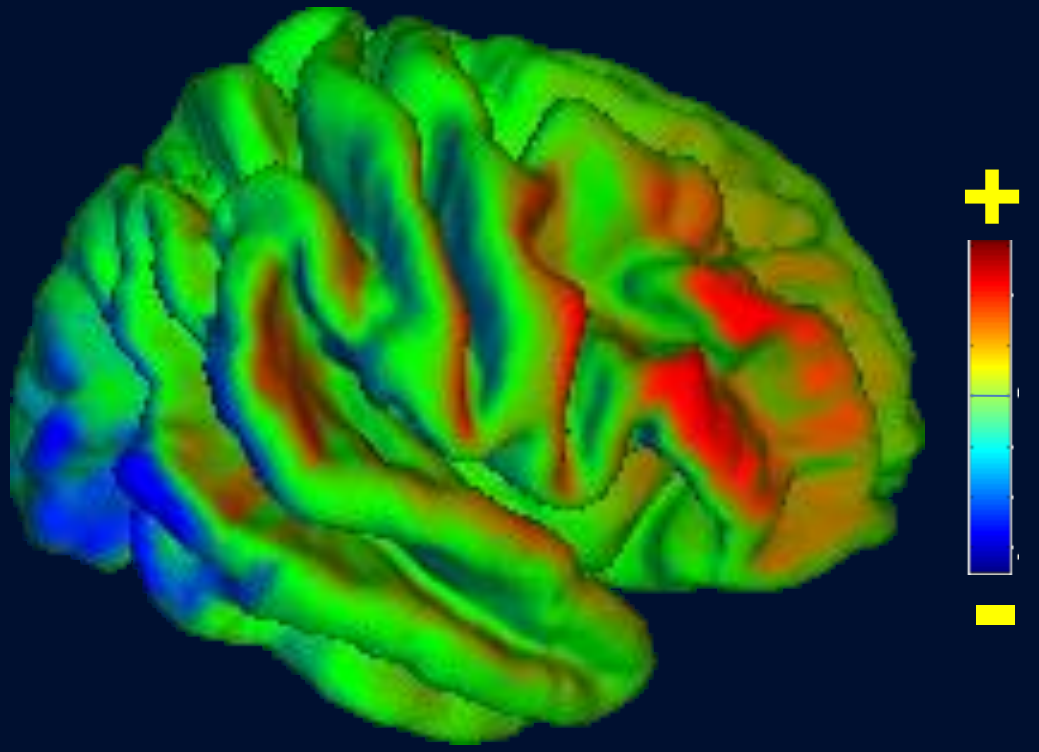
Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The ‘receptive field’ of a bipolar EEG channel



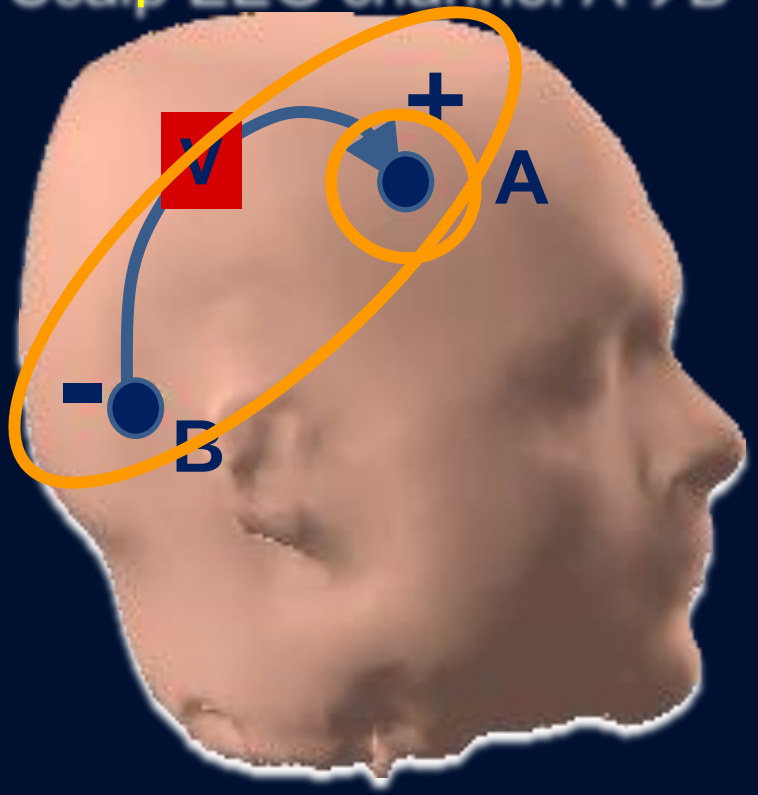
Scalp EEG channel

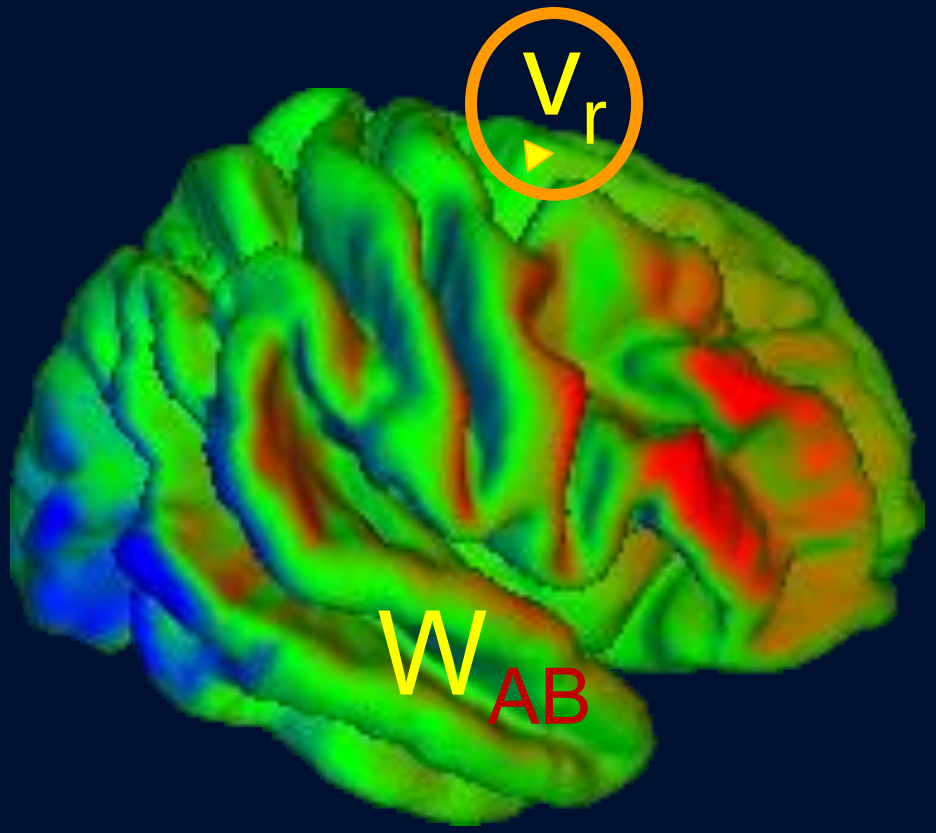


Its cortical ‘receptive field’

The ‘receptive field’ of a bipolar EEG channel!

Scalp EEG channel A→B





Its cortical ‘receptive field’

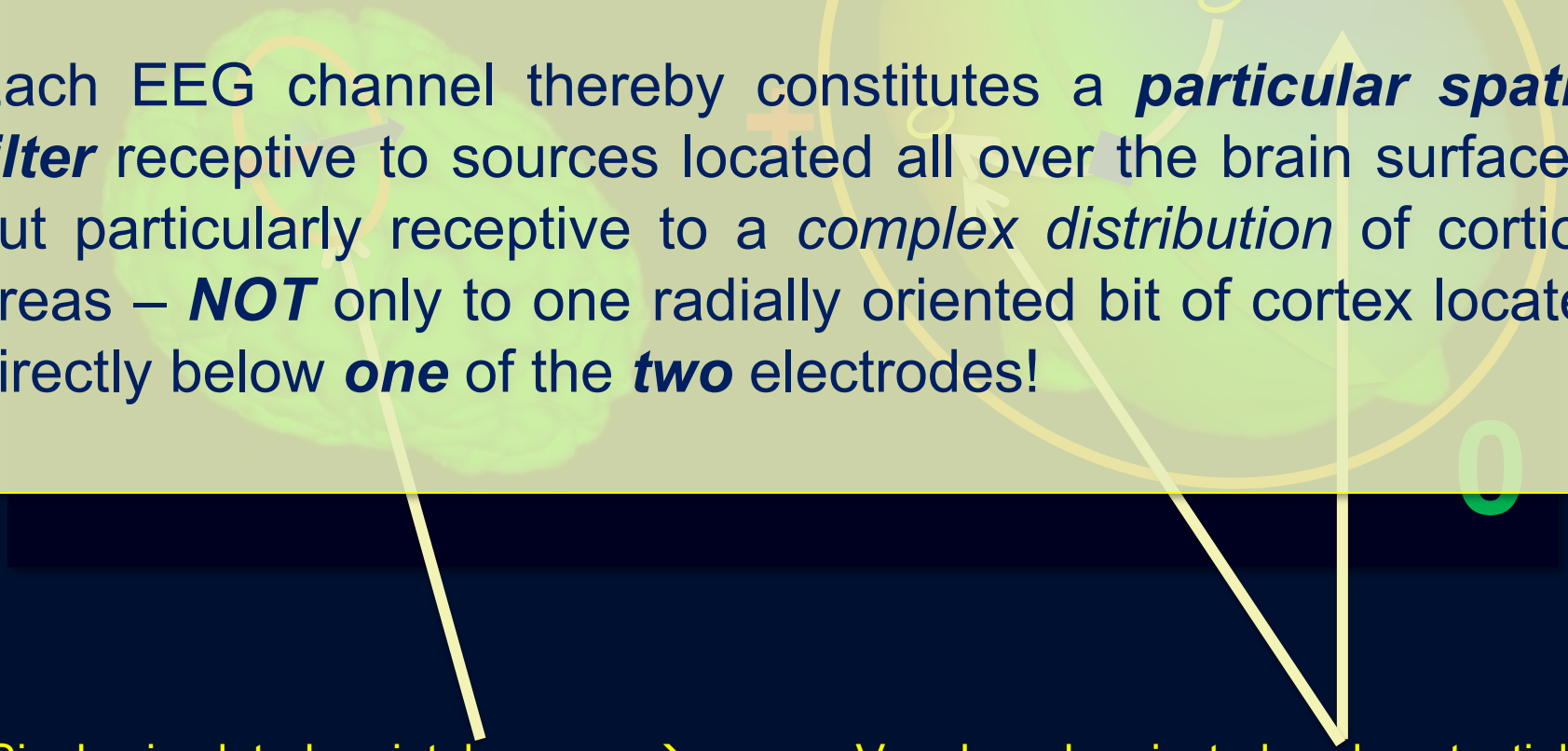
At time t,

$$V_{AB} = \sum_{r \text{ in Cortex}} v_r \times W_{AB}(r)$$

The very broad EEG point-spread function

Each EEG channel records variations in a ***double-ended voltage difference*** *between (at least)* ***two*** *electrodes*

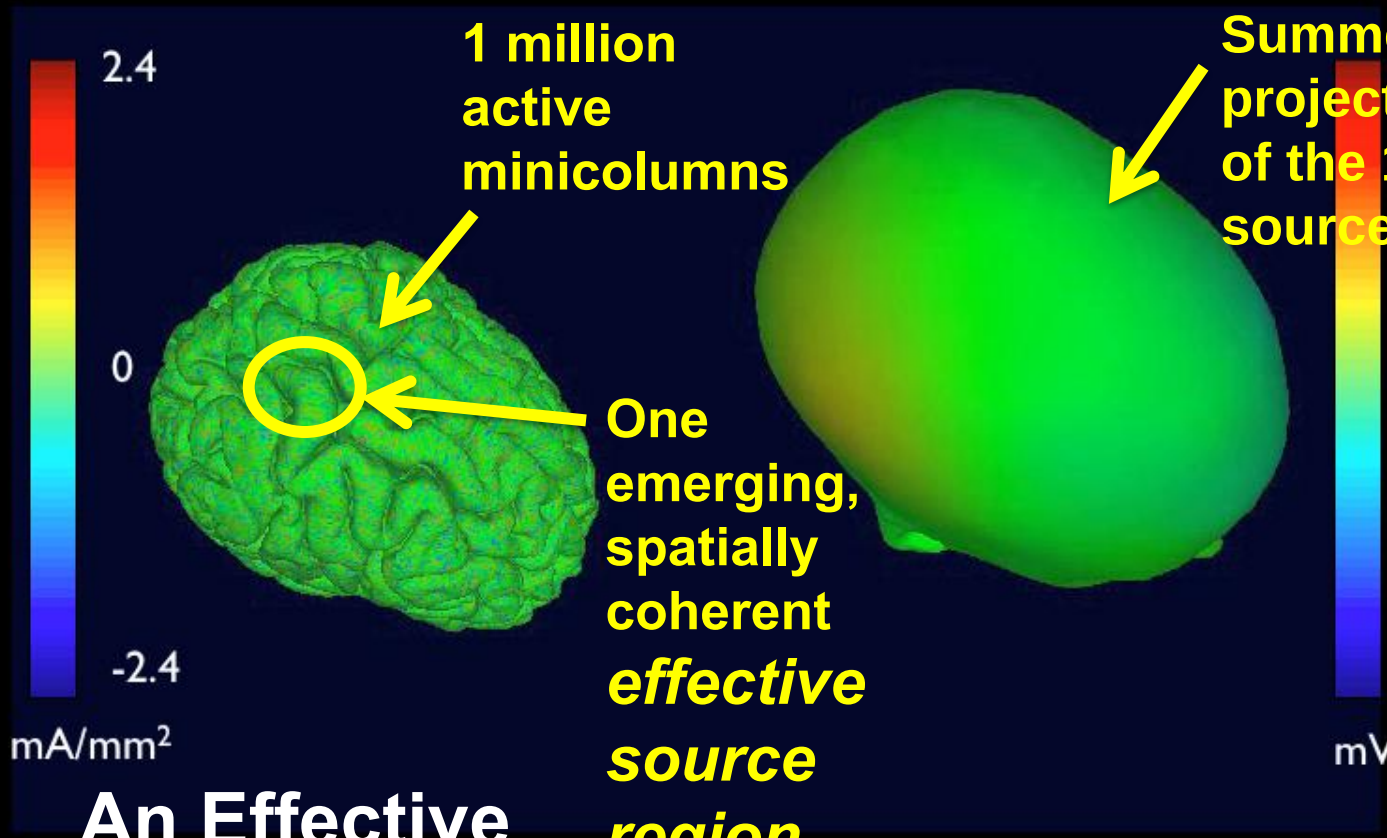
Each EEG channel thereby constitutes a ***particular spatial filter*** receptive to sources located all over the brain surface – but particularly receptive to a *complex distribution* of cortical areas – ***NOT*** only to one radially oriented bit of cortex located directly below ***one*** of the ***two*** electrodes!



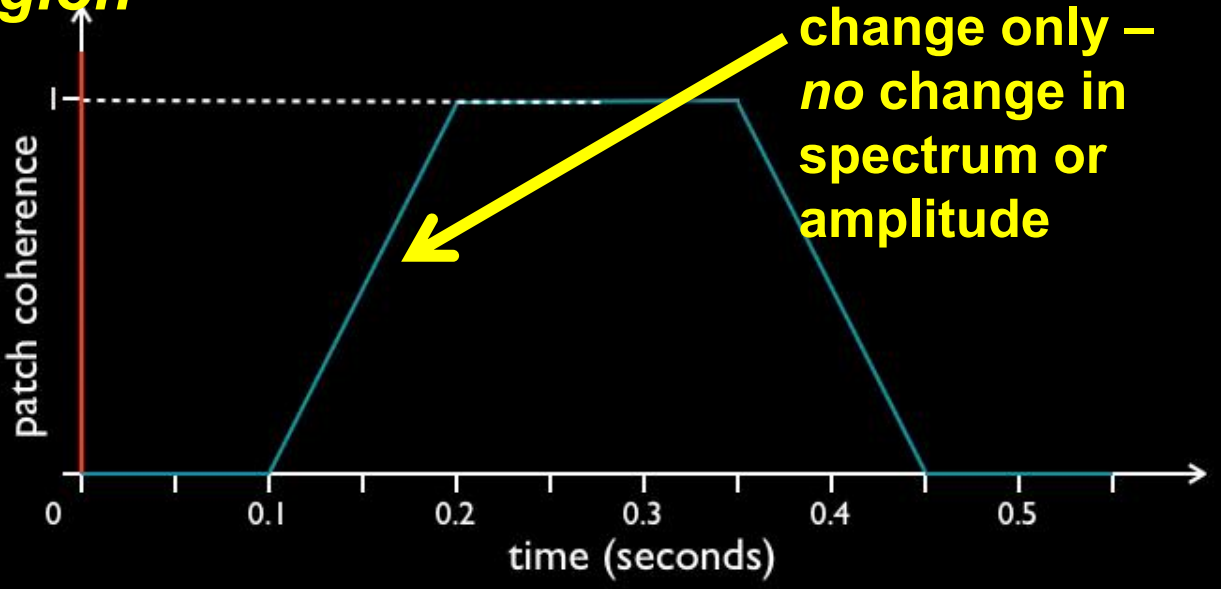
Single simulated parietal source →

Very broad projected scalp potentials

Akalin Acar & Makeig 2010

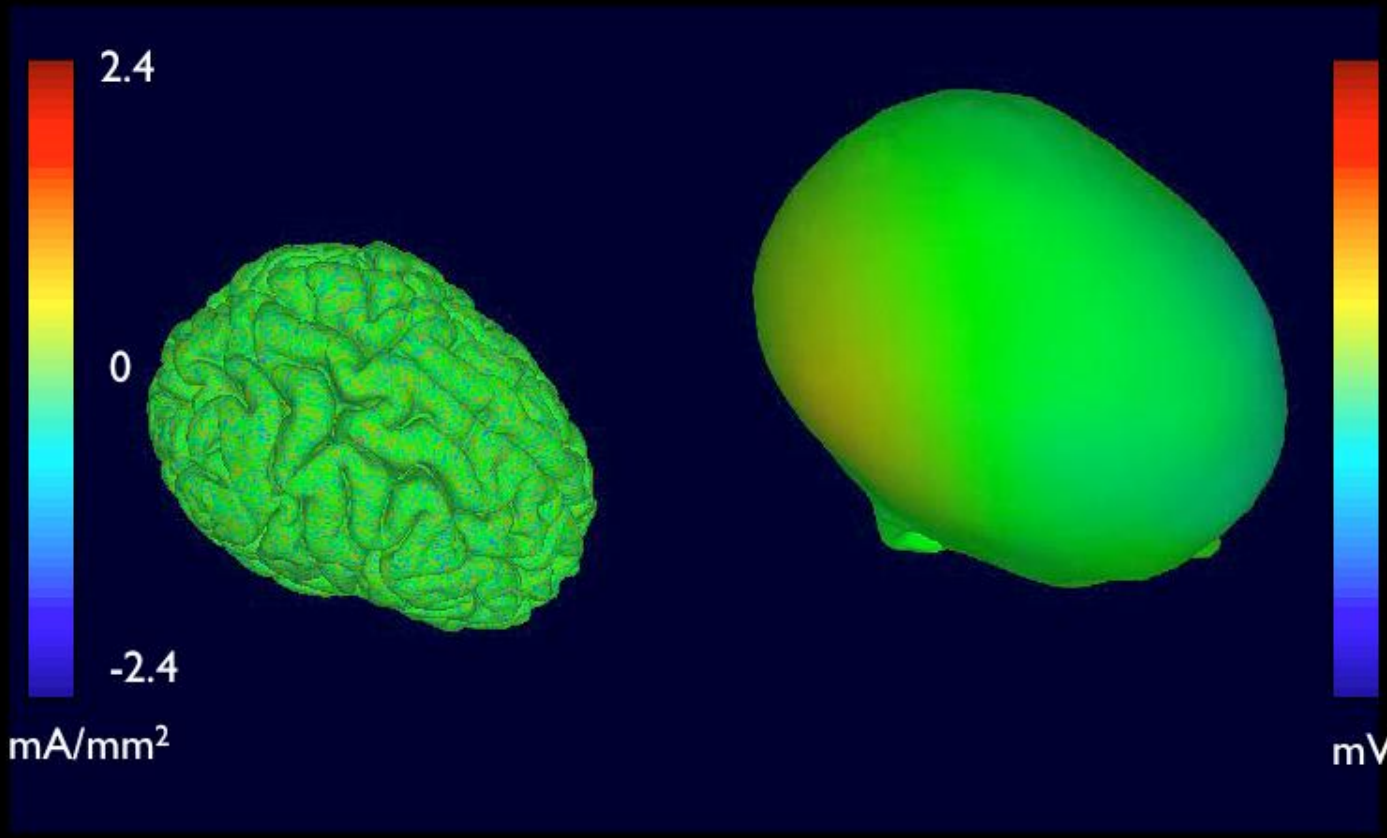


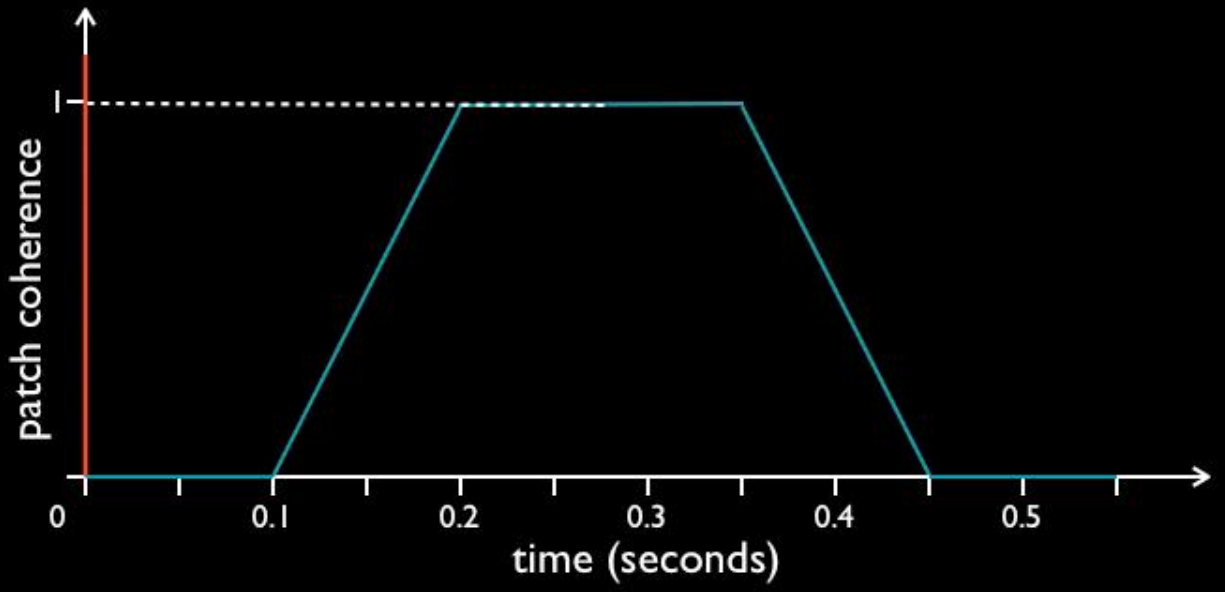
An Effective EEG Source



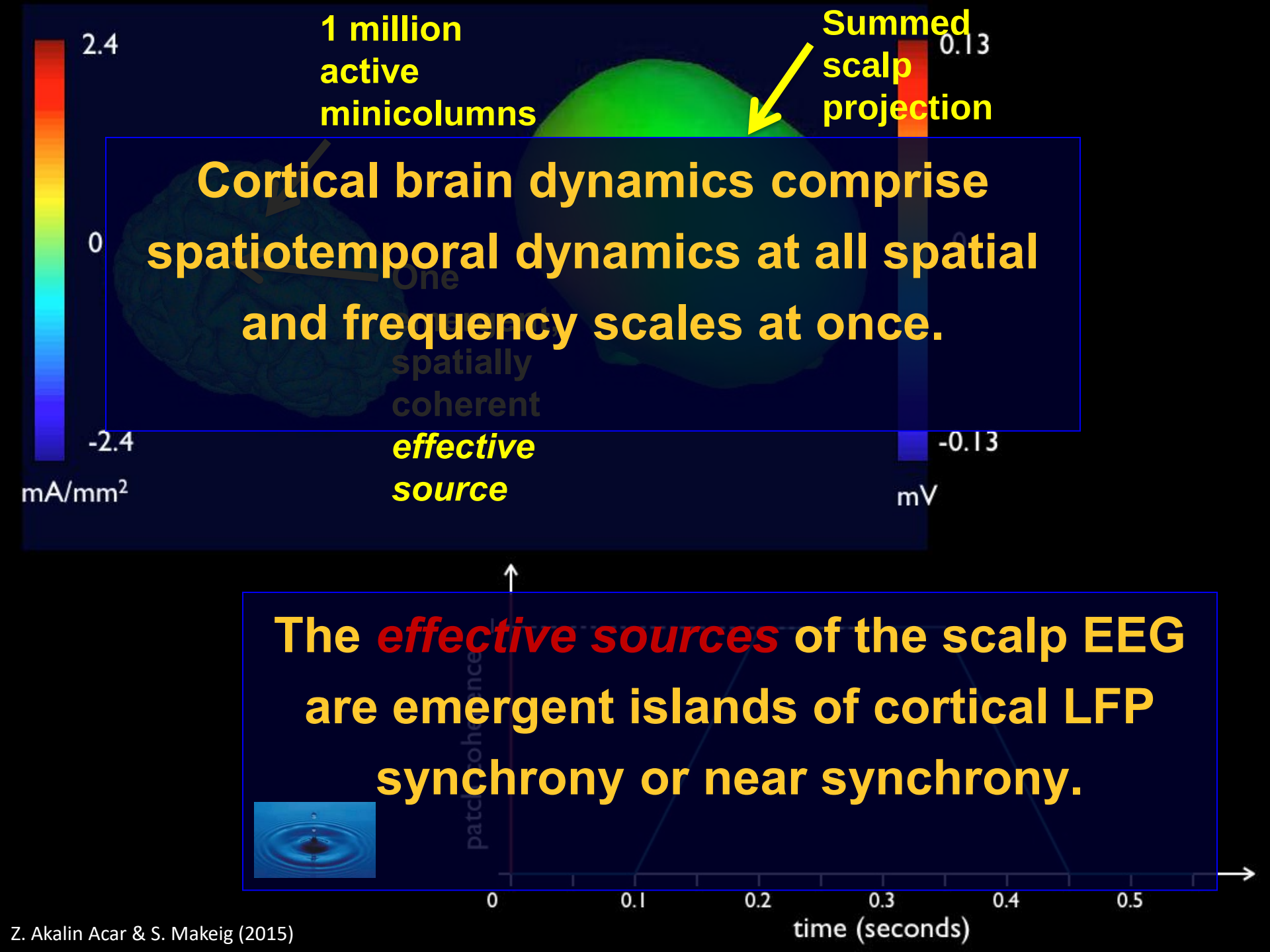
Local coherence change only – *no* change in spectrum or amplitude

Z. Akalin Acar & S. Makeig (2015)





Z. Akalin Acar & S. Makeig (2015)



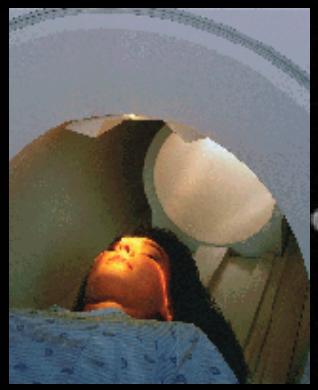
Z. Akalin Acar & S. Makeig (2015)

Electromagnetic source localization using realistic head models

NFT

Solve
for
pro
using
head
(B

T1-weighte



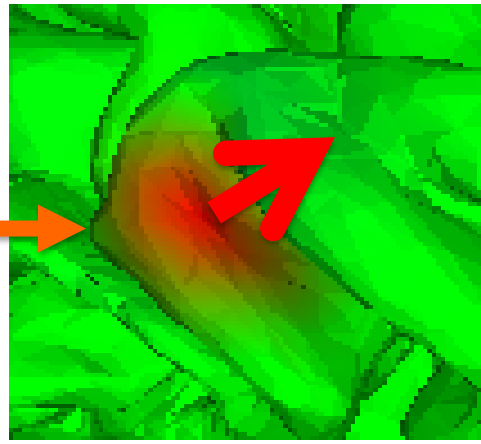
MRI

Proto

Segmentation

Simple Map

Signal Processing



Source Estimate

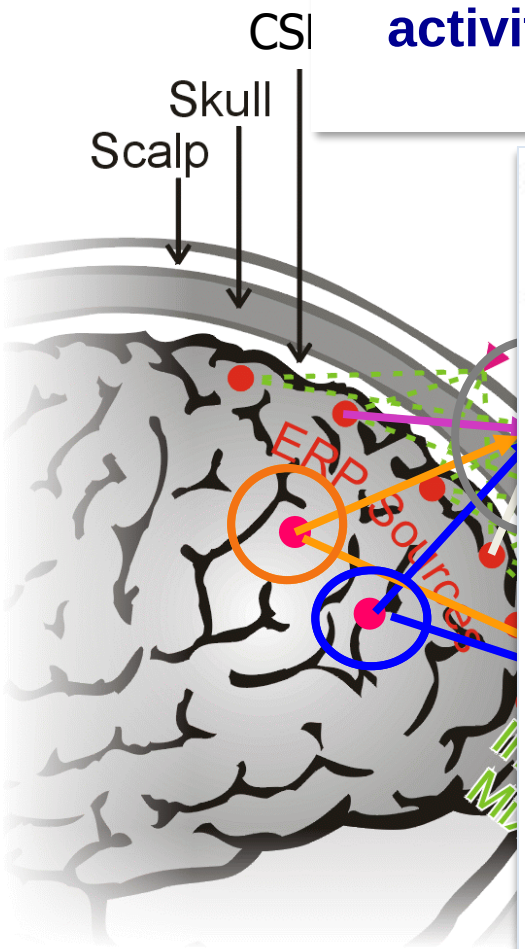
EEG/MEG

Zeynep Akalin Acar & Scott Makeig ‘06

Blind EEG Source Separation by Independent Component Analysis

Tony Bell, developer of Infomax ICA

ICA can find distinct EEG source activities -- and their 'simple' scalp maps!



Independent Component Analysis of Electroencephalographic Data

Scott Makeig
Naval Health Research Center
P.O. Box 85122
San Diego CA 92186-5122
scott@sccn.nosc.mil

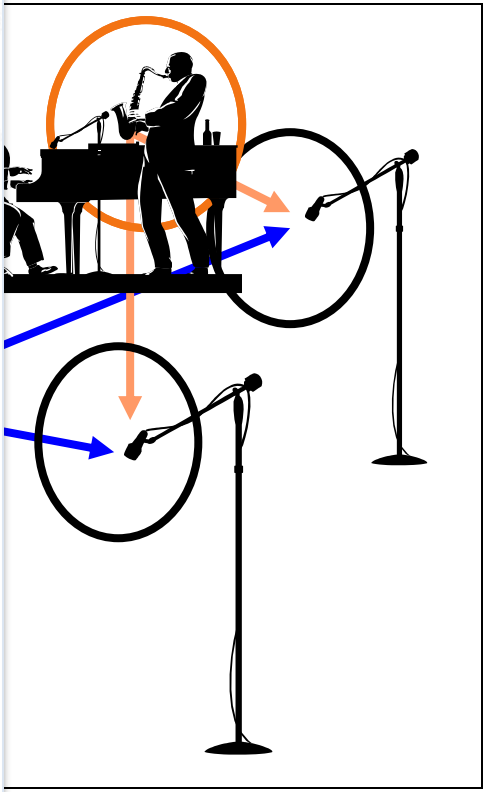
Anthony J. Bell
Computational Neurobiology Lab
The Salk Institute, P.O. Box 85800
San Diego, CA 92186-5800
tony@salk.edu

Tzyy-Ping Jung
Naval Health Research Center and
Computational Neurobiology Lab
The Salk Institute, P.O. Box 85800
San Diego, CA 92186-5800
jung@salk.edu

Terrence J. Sejnowski
Howard Hughes Medical Institute and
Computational Neurobiology Lab
The Salk Institute, P.O. Box 85800
San Diego, CA 92186-5800
terry@salk.edu

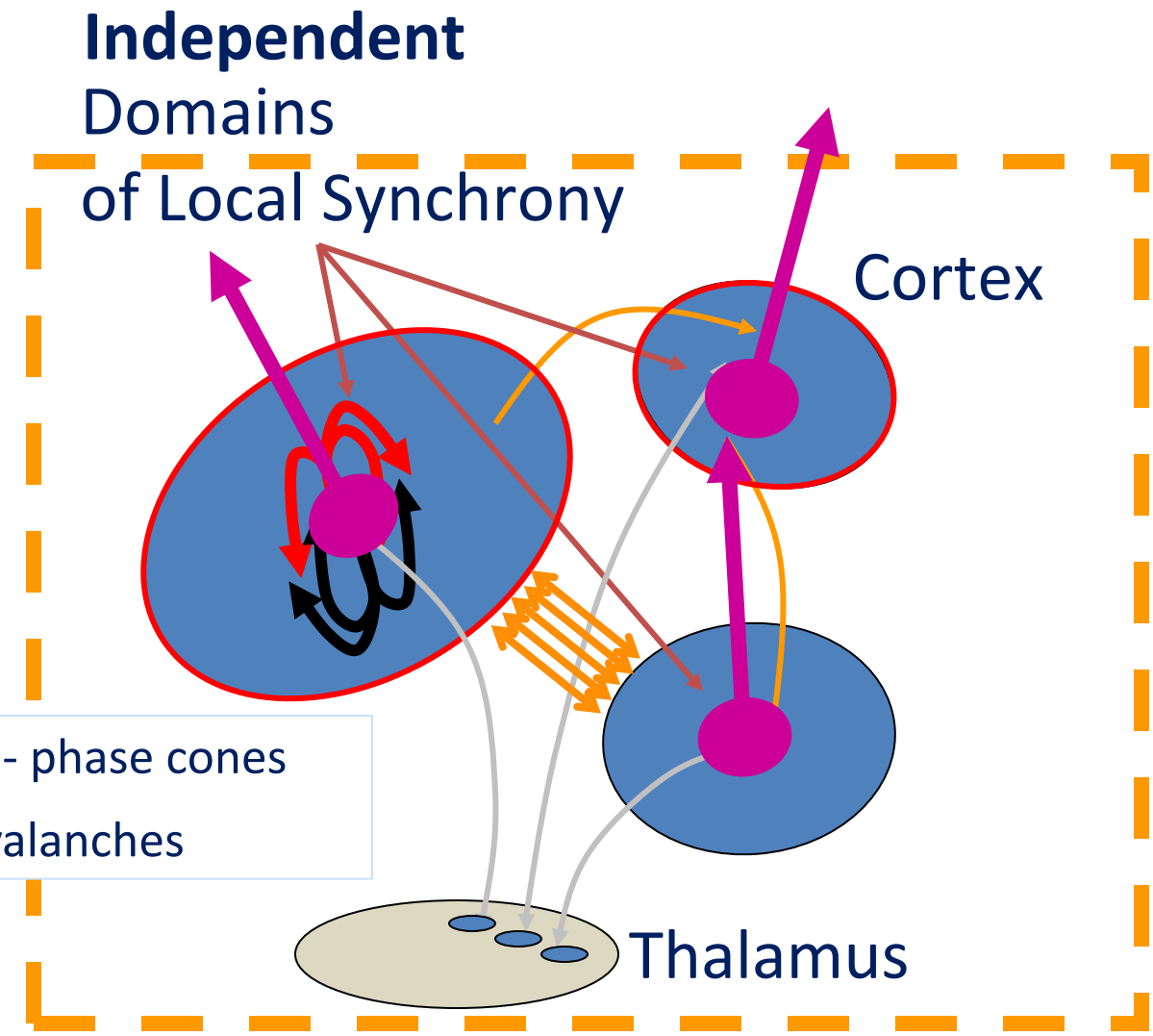
Abstract

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.



S. Makeig, S. Enghoff (2000)

Are EEG effective source signals *temporally independent*?



Freeman - phase cones

Plenz - avalanches

S. Makeig (2007)

The EEG Inverse Problem is Twofold

What & *where* is this Effective source?

Identification → Localization

ICA gives a model-based response to the 1st question:

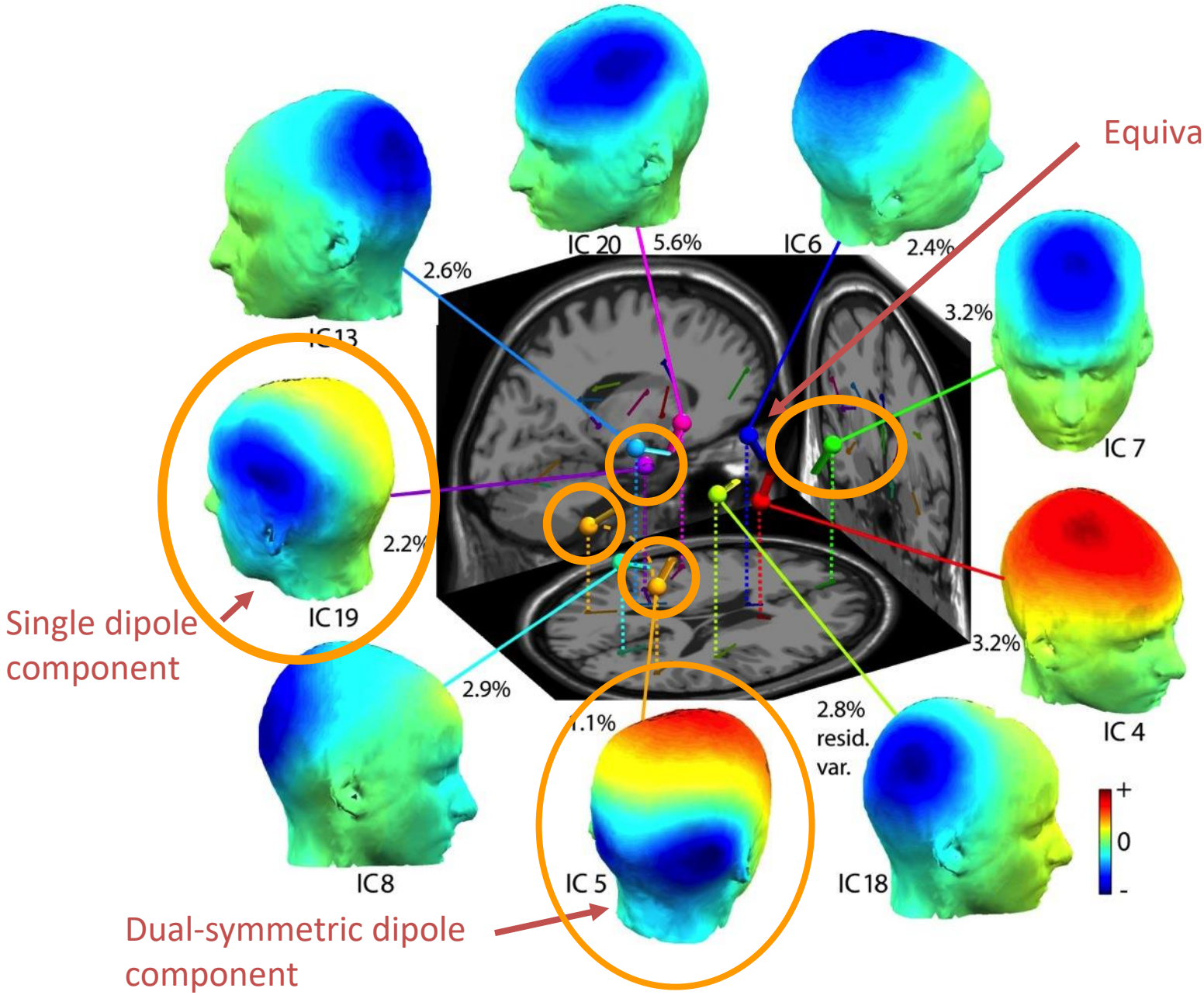
- ***What*** **are the effective sources? (identification)**

And for *effective brain sources*, it helps answer the 2nd:

- ***Where*** **do these sources originate? (localization)**

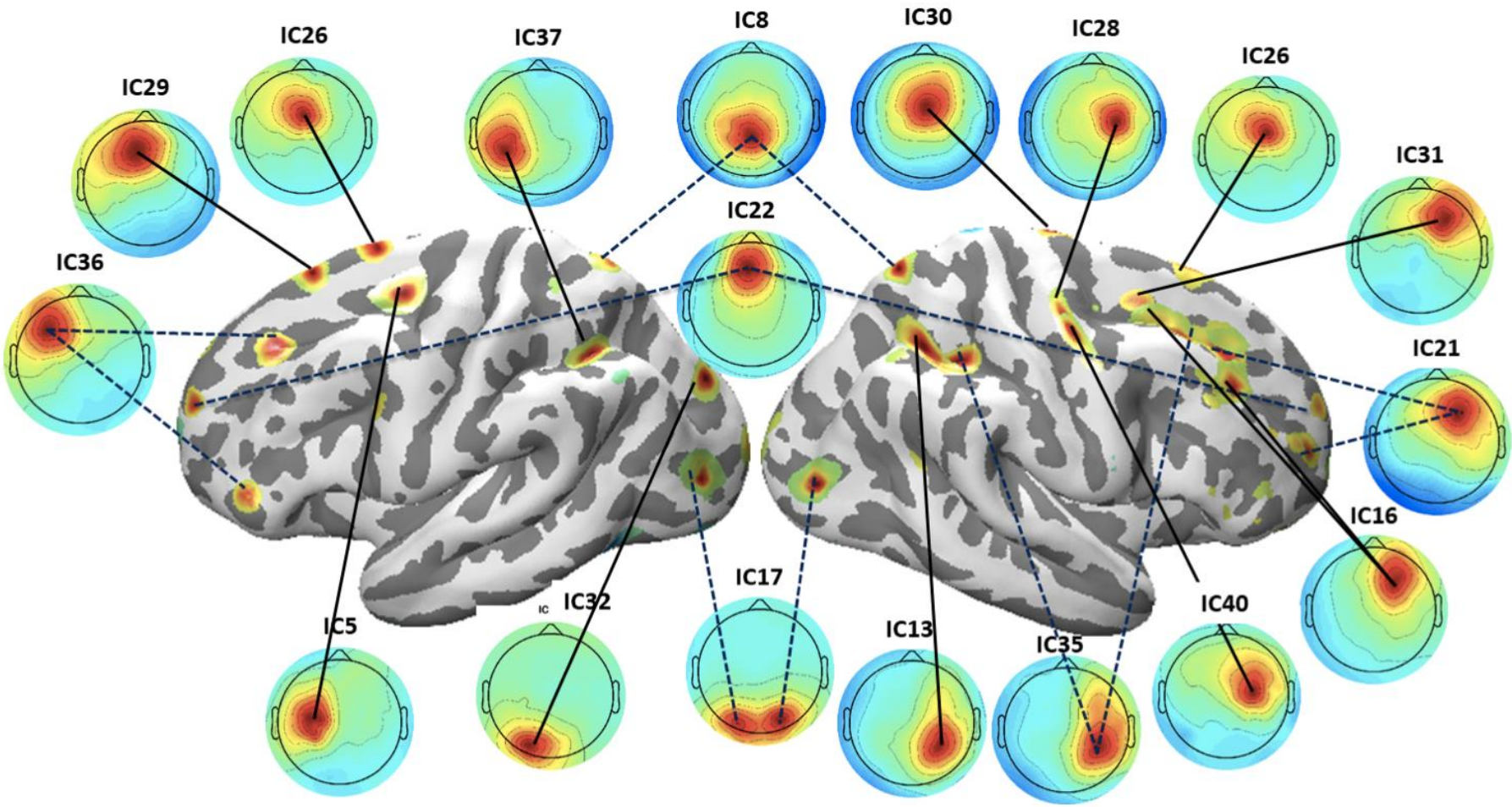
IC Classification Problem

Nine IC effective brain sources



Julie Onton & S. Makeig (2006)

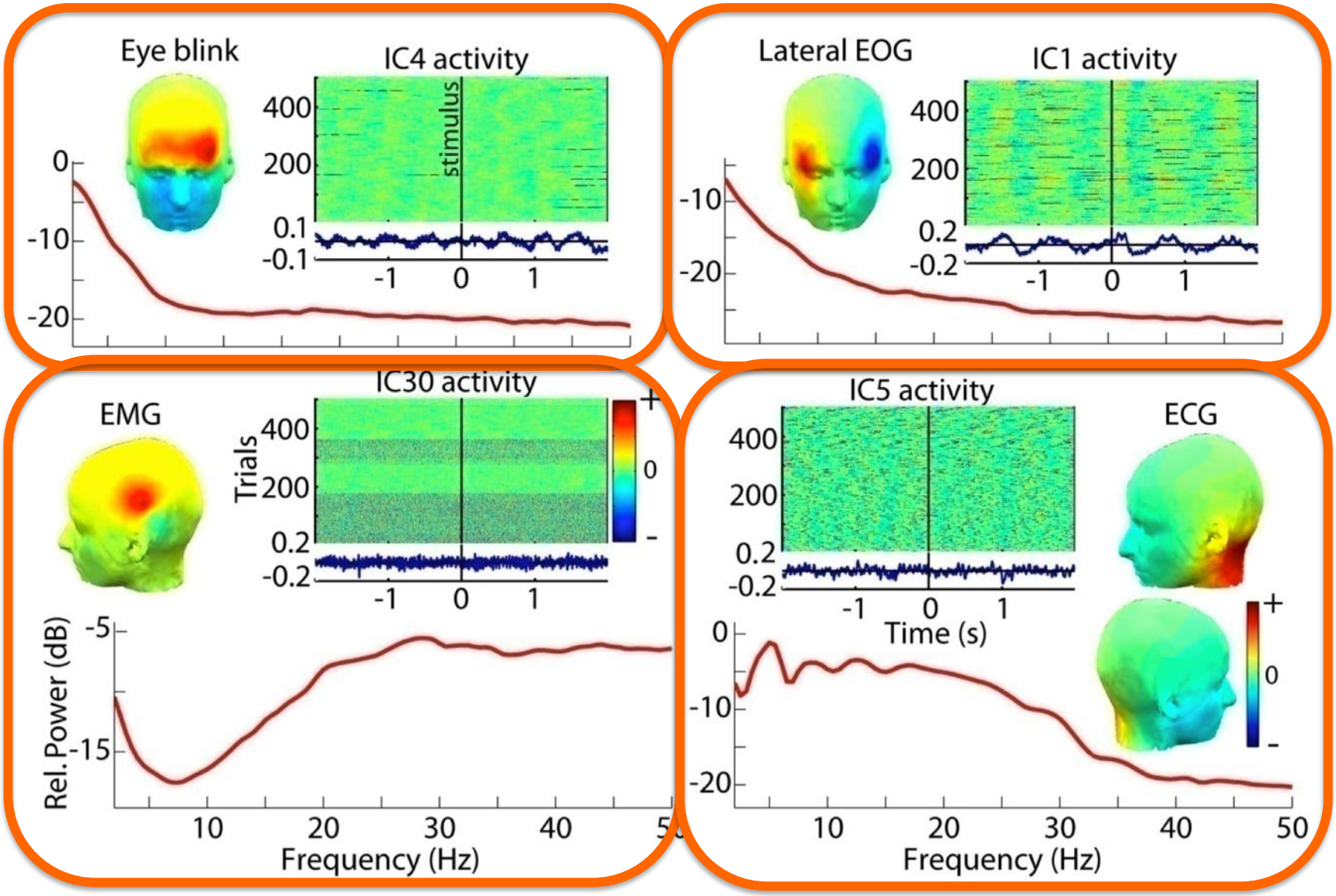
ICA effective source distributions localized by SCALE



Participant P6: STRUM videogame playing task

Zeynep Akalin Acar & S Makeig, 2020

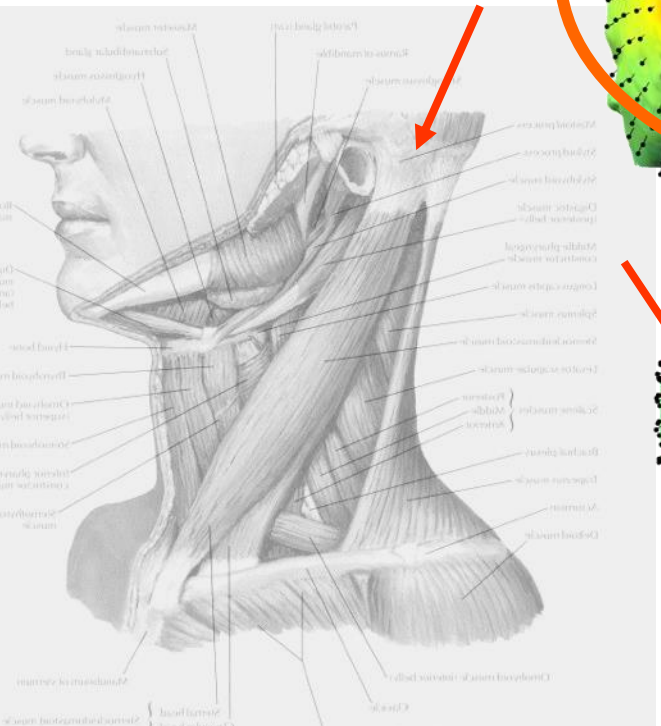
ICA finds non-brain independent component (IC) processes …

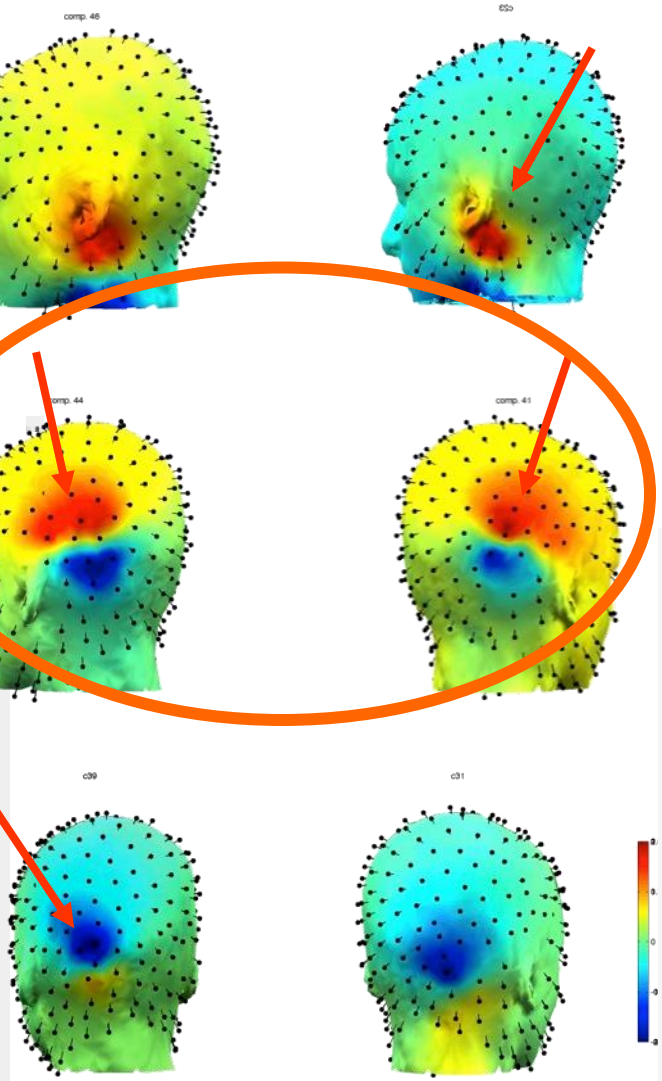


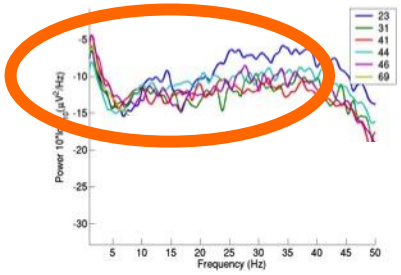
… separates them from the remainder of the data …

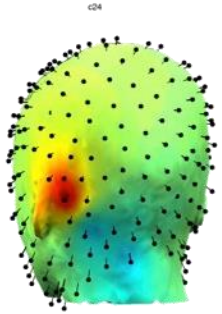
J. Onton & S. Makeig 2006

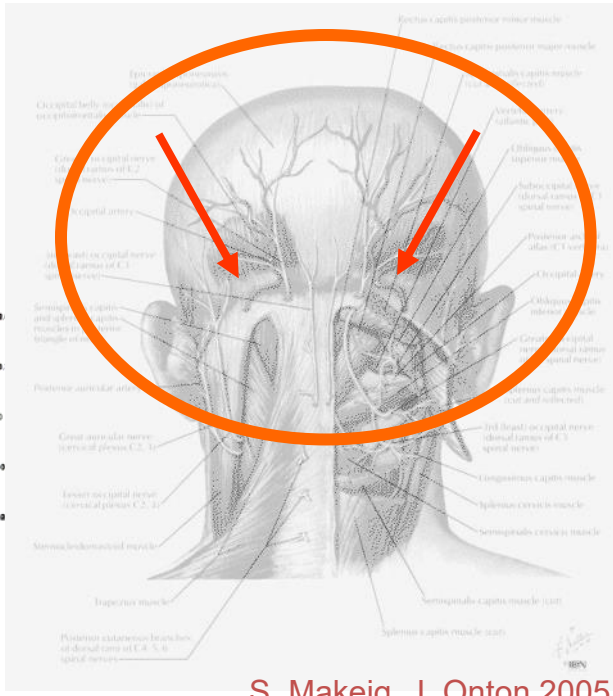
… including IC EMG sources





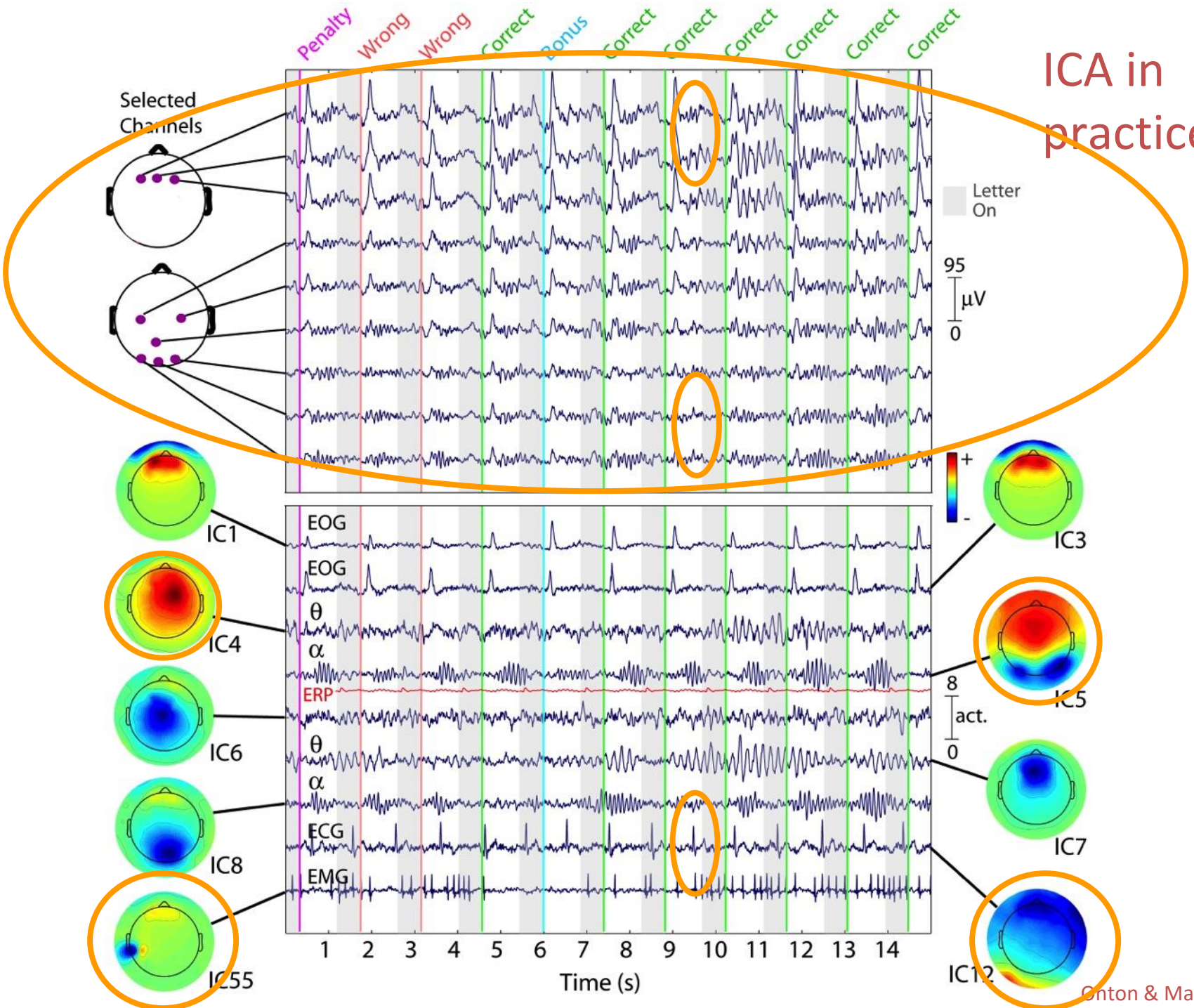






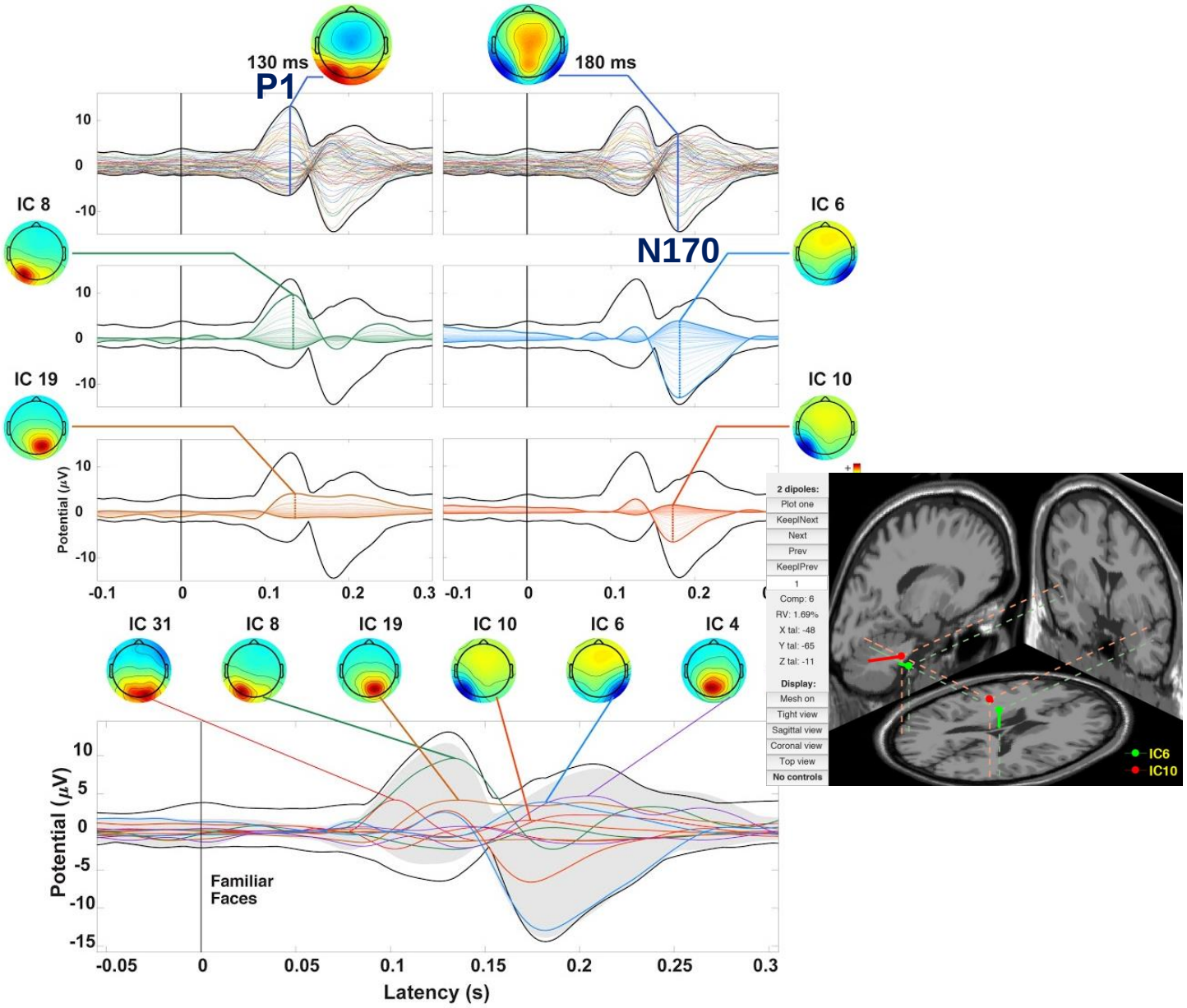
S. Makeig, J. Onton 2005

ICA in practice



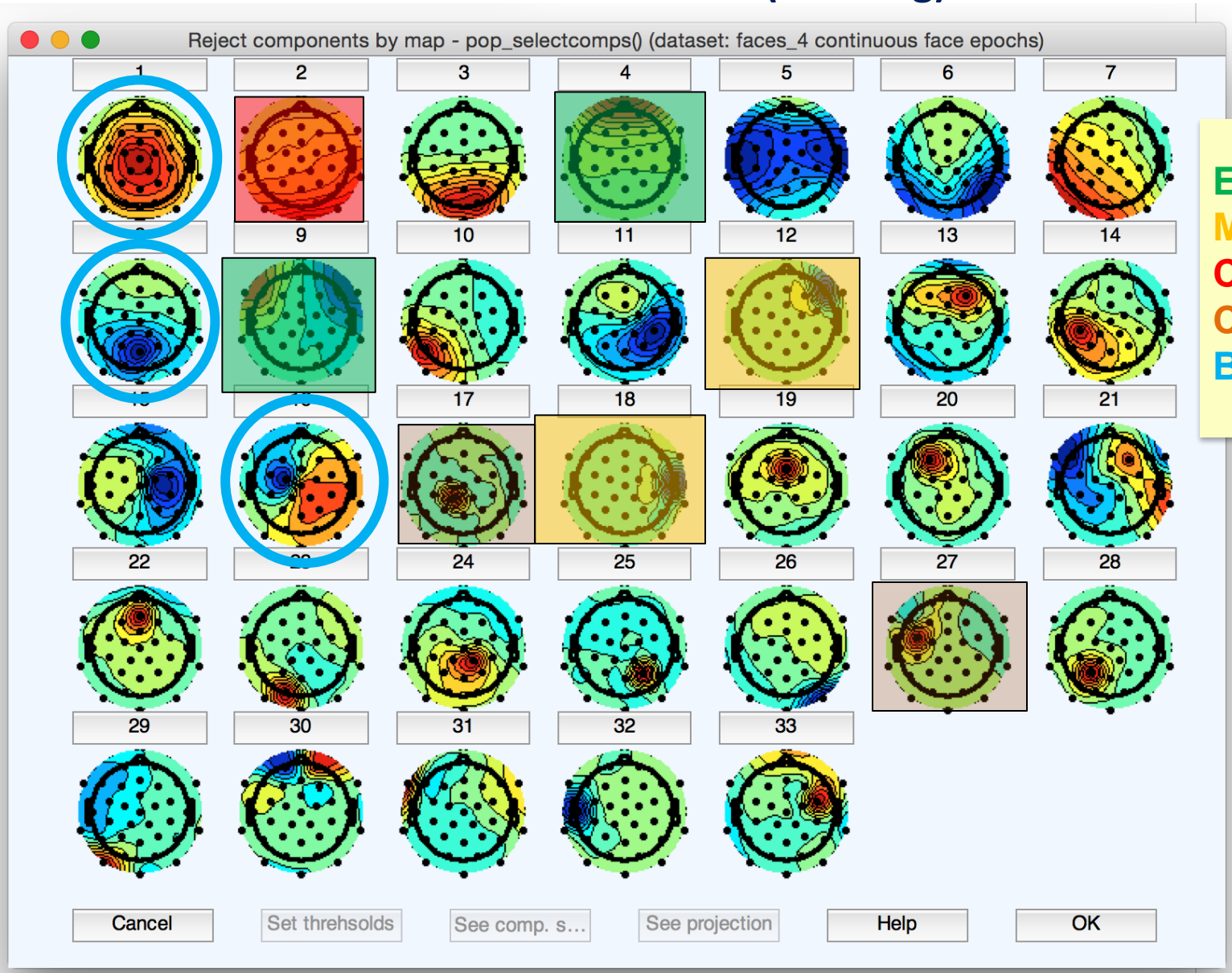
Onton & Makeig, 2006

Henson & Wakeman Face-ERP (S11)



Martinez-Cancino in prep.

IC Classification (Labeling)

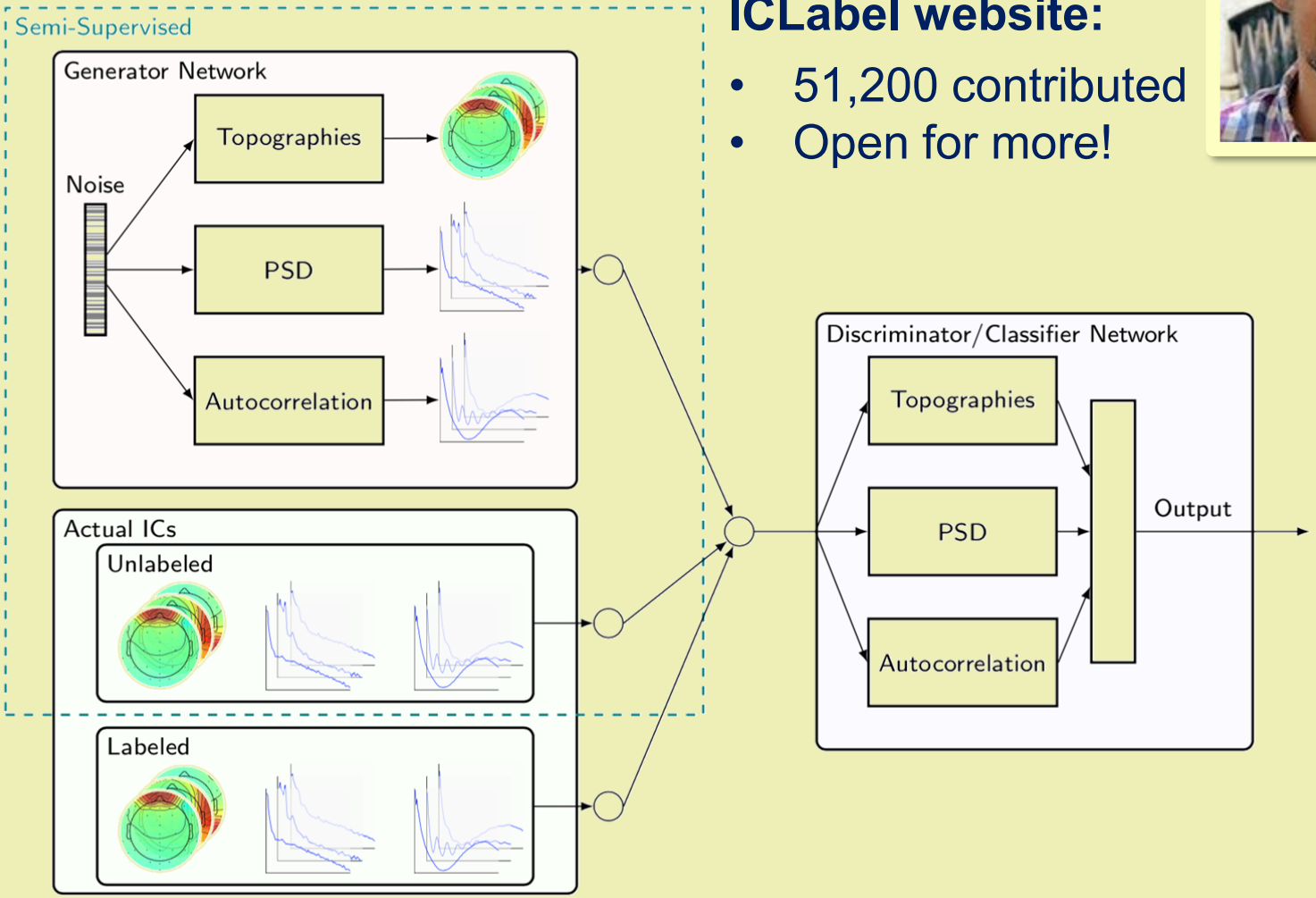


Eye
Muscle
Cardiac
Chan noise
Brain

ICLabel

ICLabel website:

- 51,200 contributed
- Open for more!

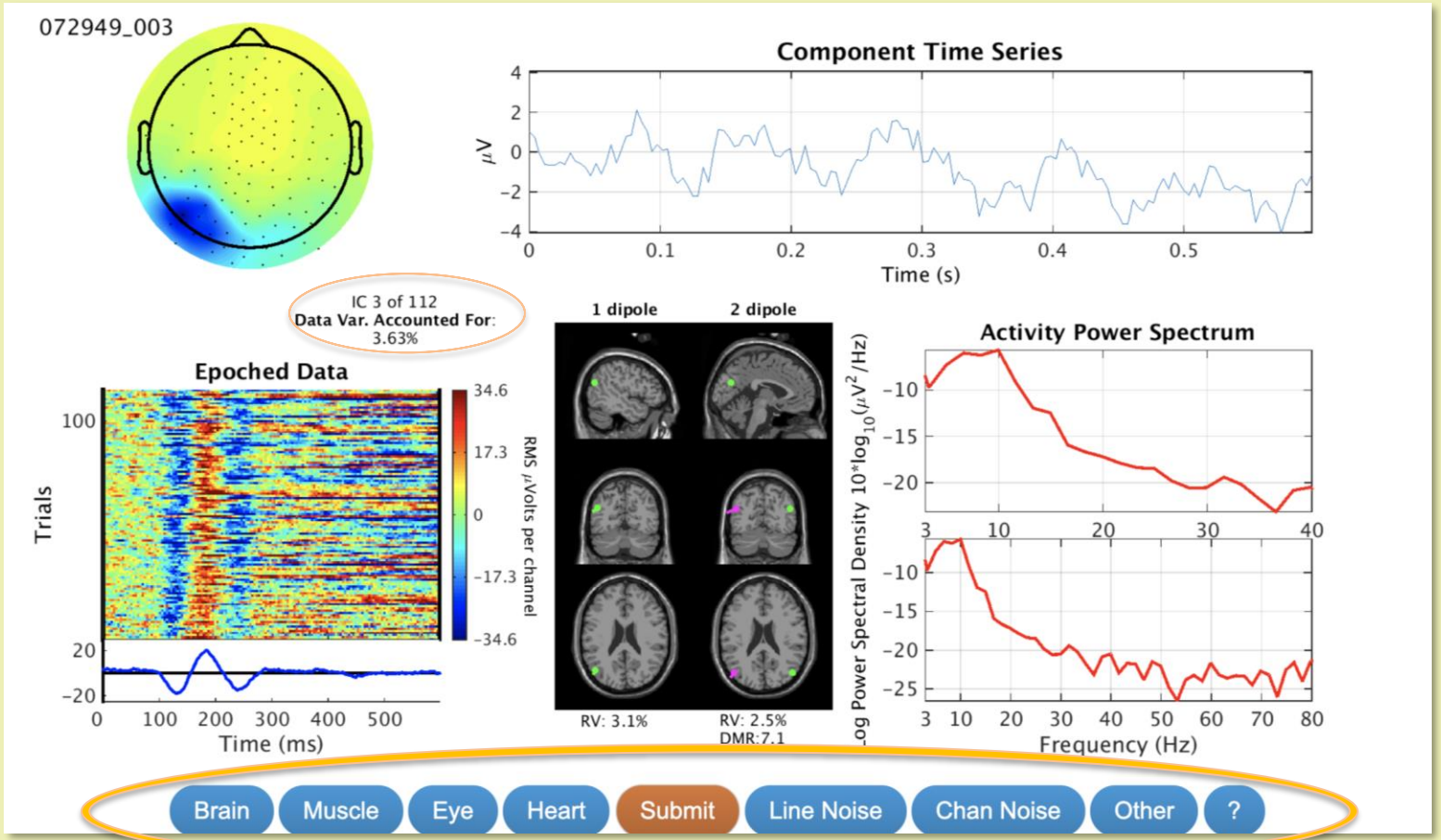


https://labeling.ucsd.edu/tutorial

Luca Pion-Tonachini, 2019

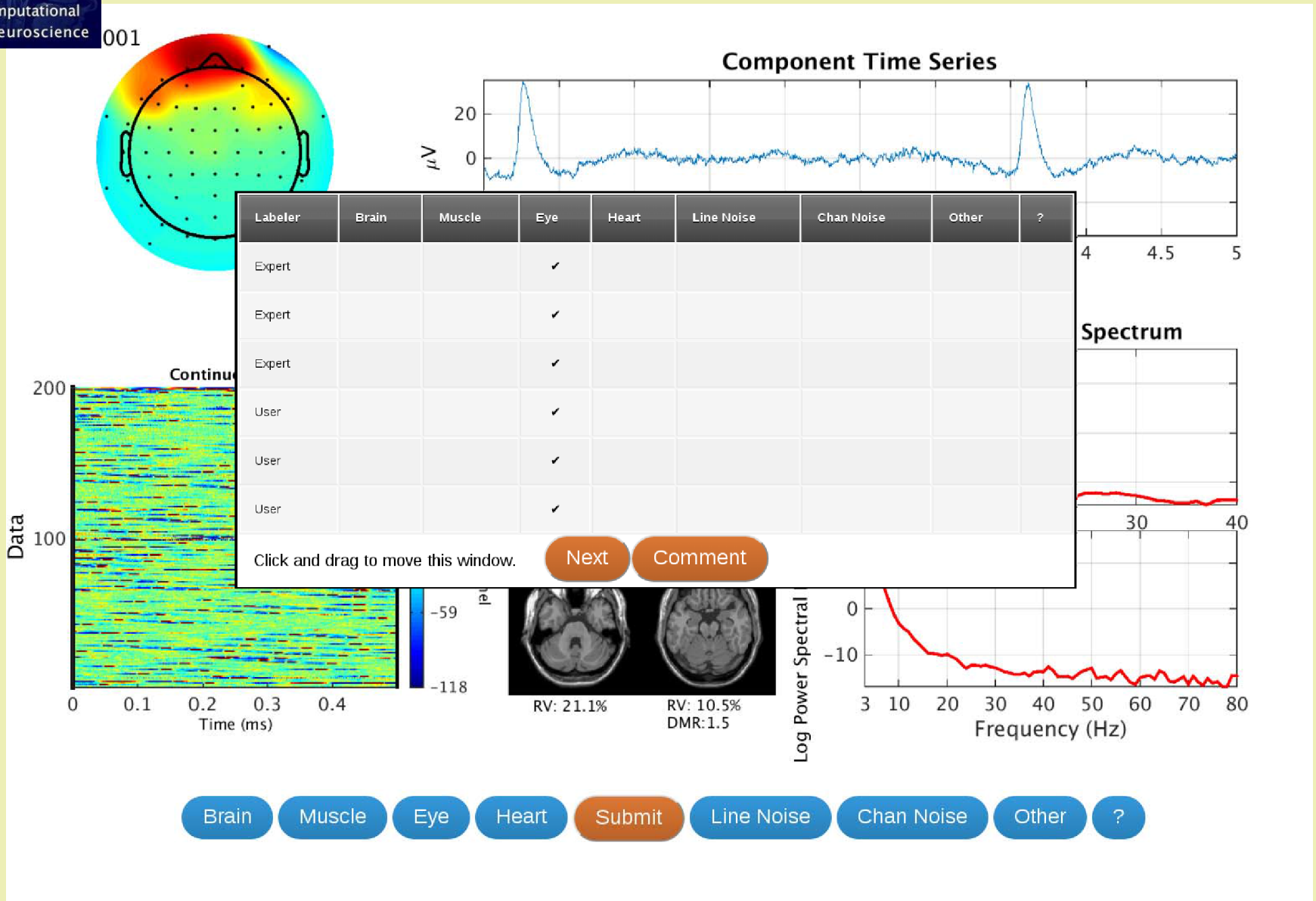
The ICLabel Tutorial Website

https://labeling.ucsd.edu/tutorial



Luca Pion-Tonachini, 2019

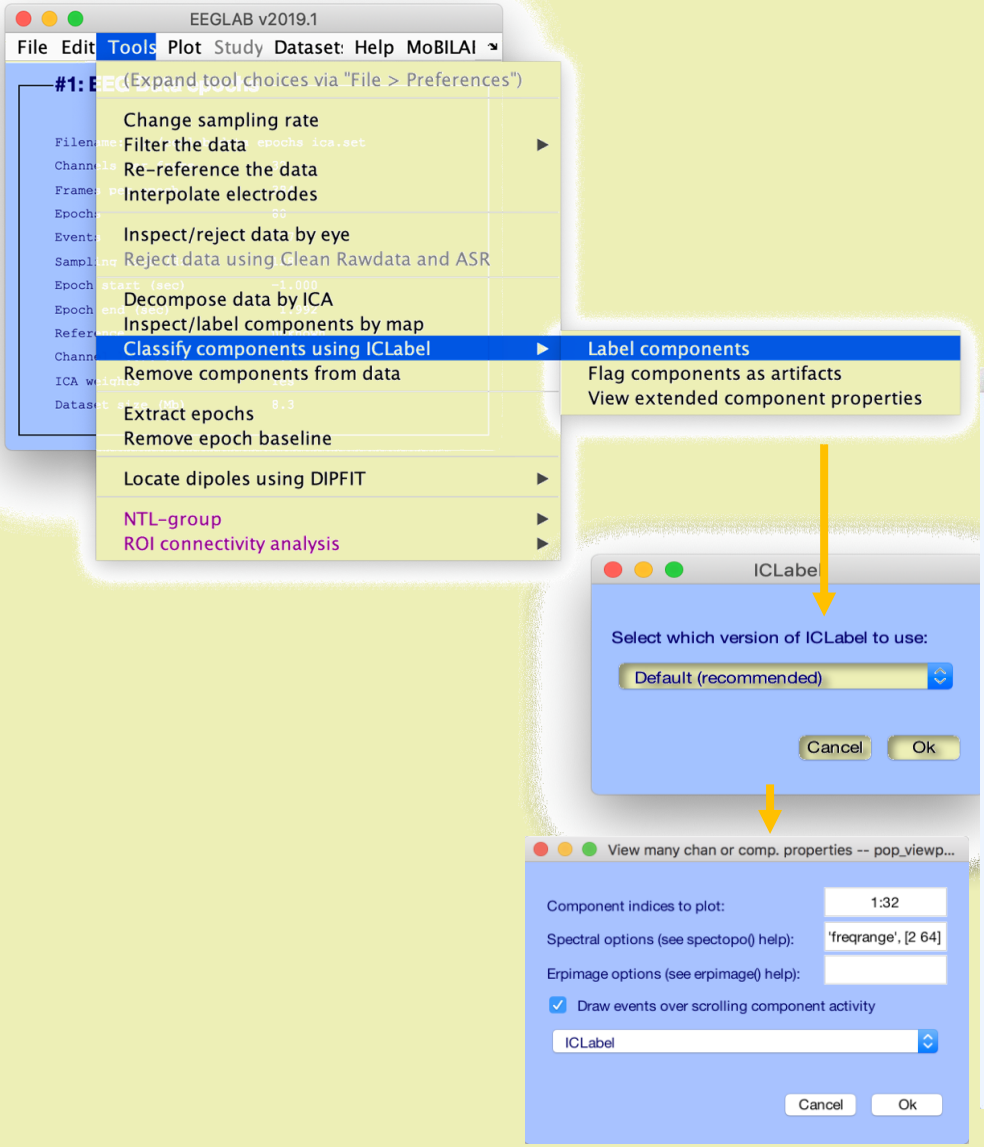
ICLabel



Luca Pion-Tonachini, 2019

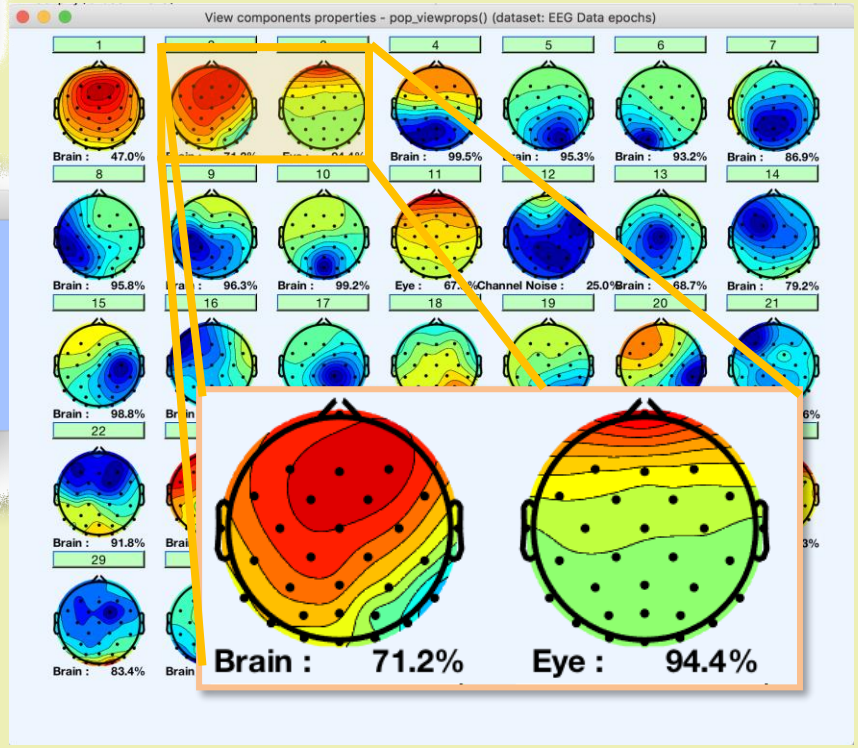
Using the ICLabel Plug-in

Swartz Center for Computational Neuroscience



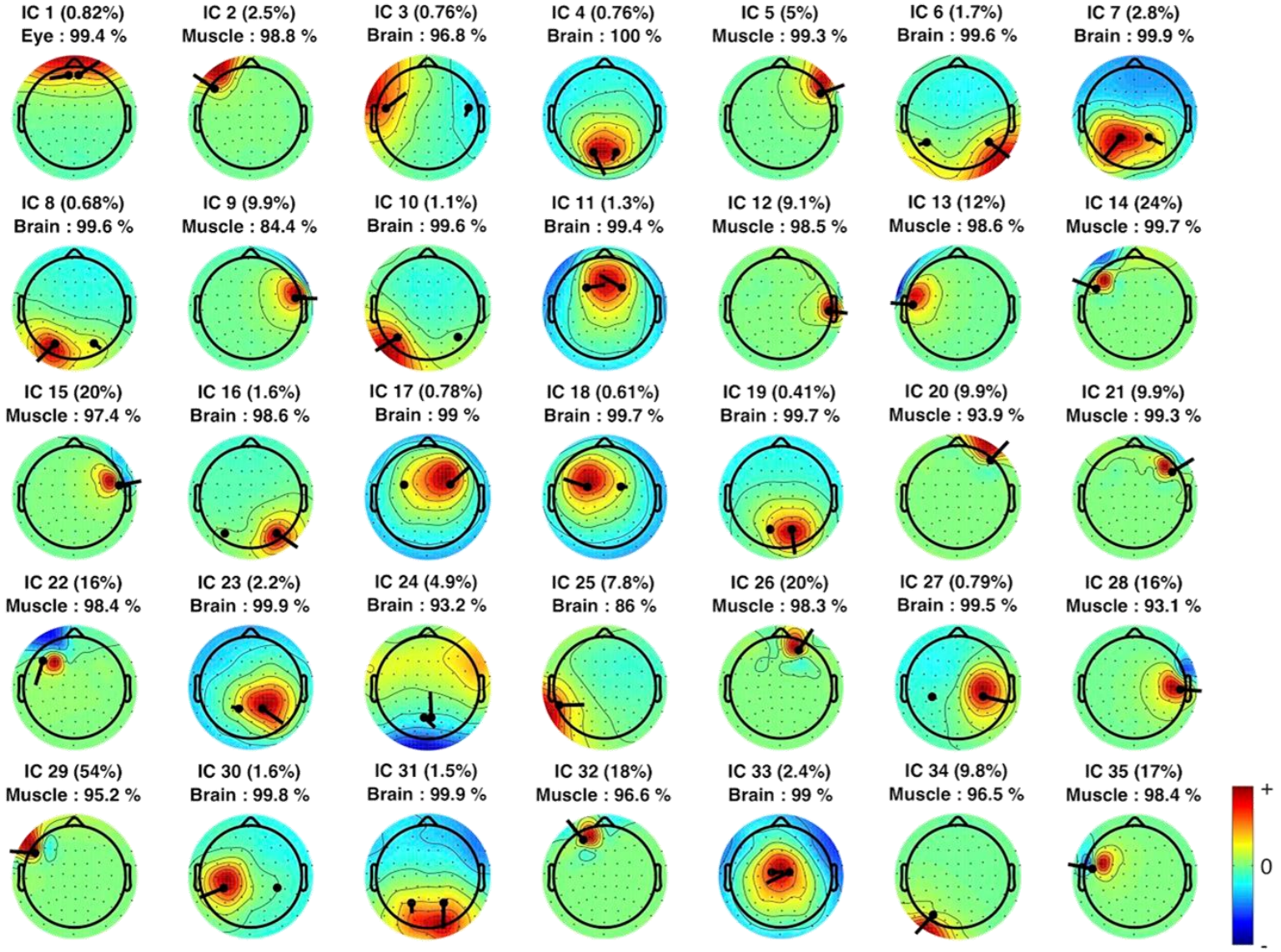
Component types

- **Brain**
- **Muscle**
- **Eye**
- **Heart**
- **Line Noise**
- **Channel Noise**
- **Other**



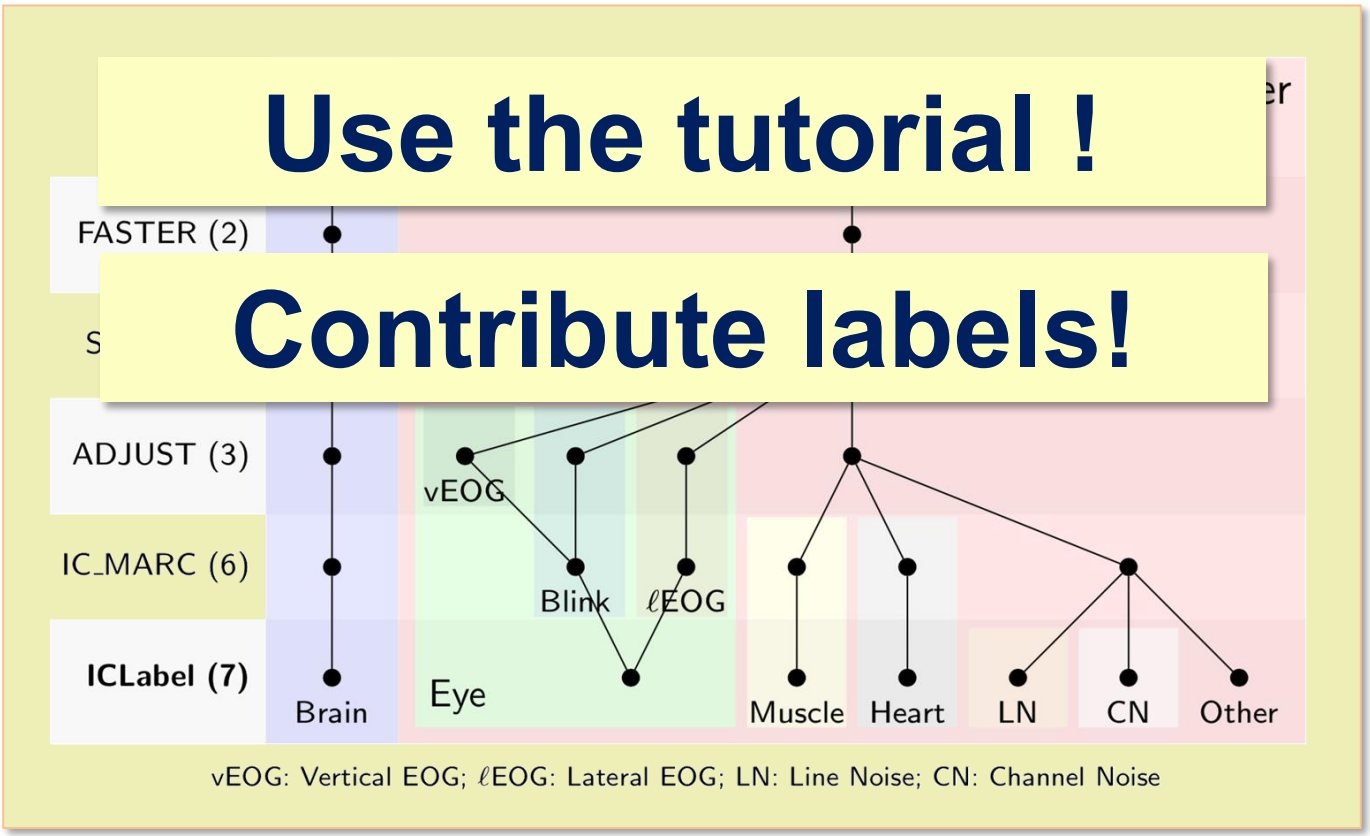
Luca Pion-Tonachini, 2019

Henson & Wakeman Face-ERP (S11)



Martinez-Cancino in prep.

ICLabel



Pion-Tonachini, Luca et al. (2019) ICLabel: An automated electroencephalographic independent component classifier, dataset, and website. *NeuroImage*, 98:181-197. doi: 10.1016/j.neuroimage.2019.05.026.

Swartz Center for Computational Neuroscience

https://labeling.ucsd.edu/tutorial

The Beginning

Neuro
Electro
Magnetic
Brain Dynamics!

smakeig@ucsd.edu