EEG Data Mining I: Toward High-Resolution EEG Source Imaging

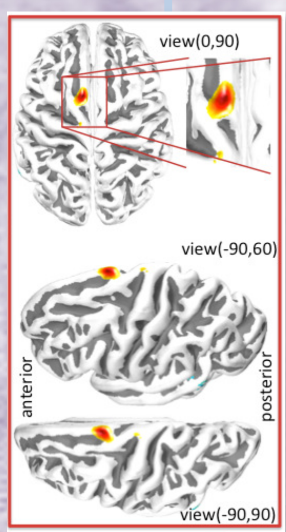
Scott Makeig

Institute for Neural Computation

University of California San Diego

35th EEGLAB Workshop

UCSD
La Jolola, California
November 18-21, 2022



Mining Event-related Brain Dynamics I

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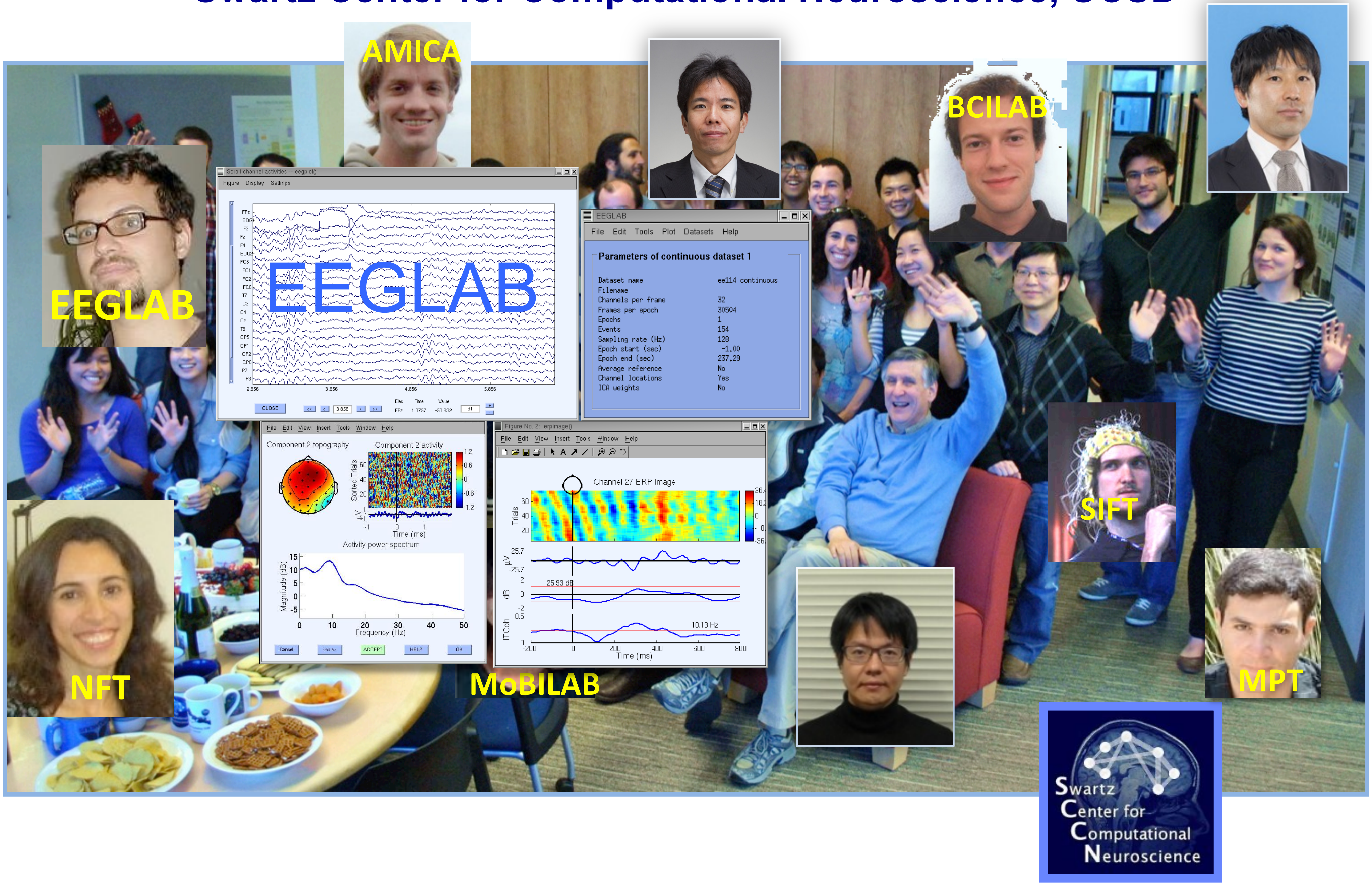
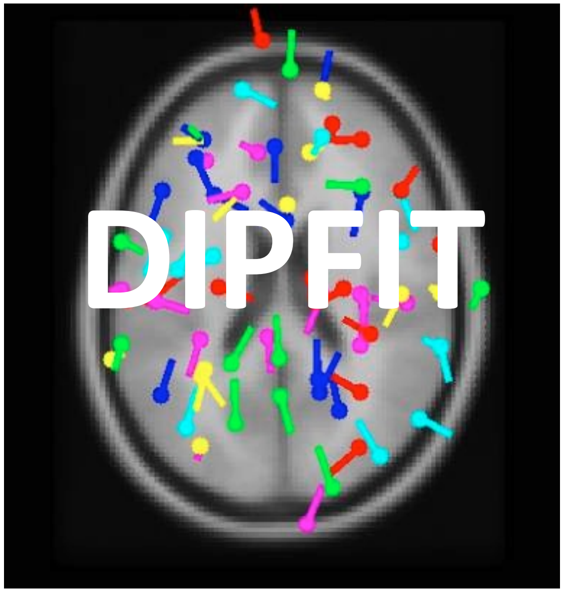
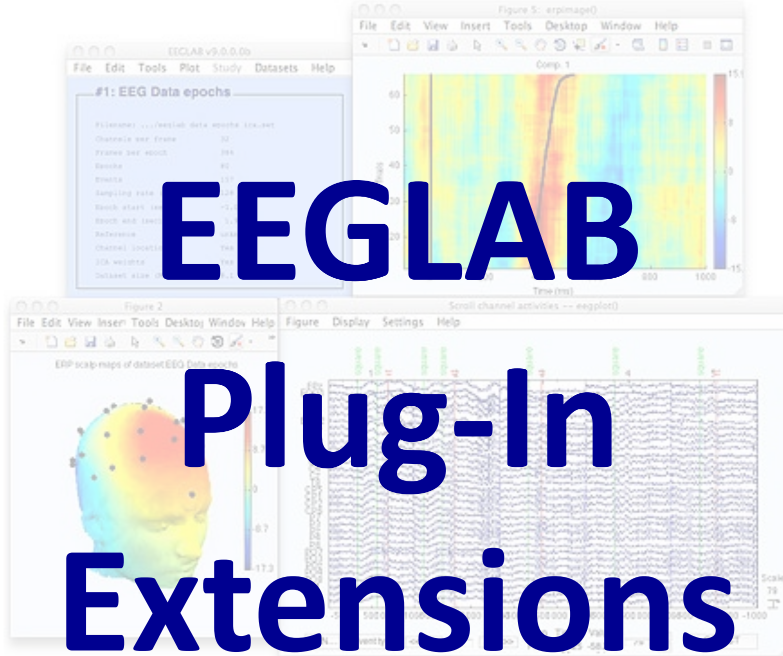
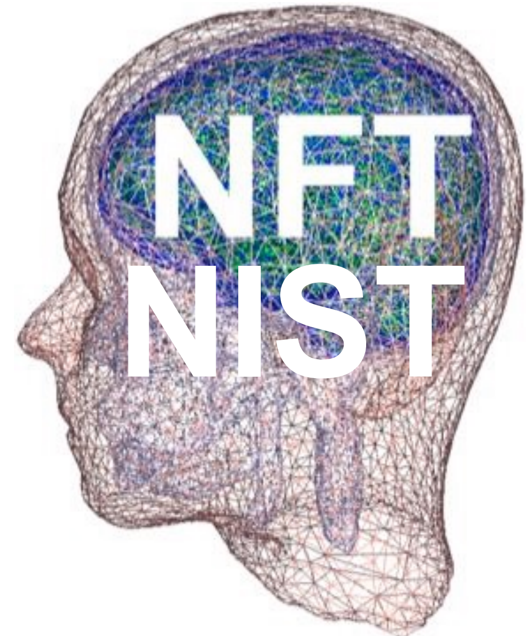
Swartz Center for Computational Neuroscience, UCSD

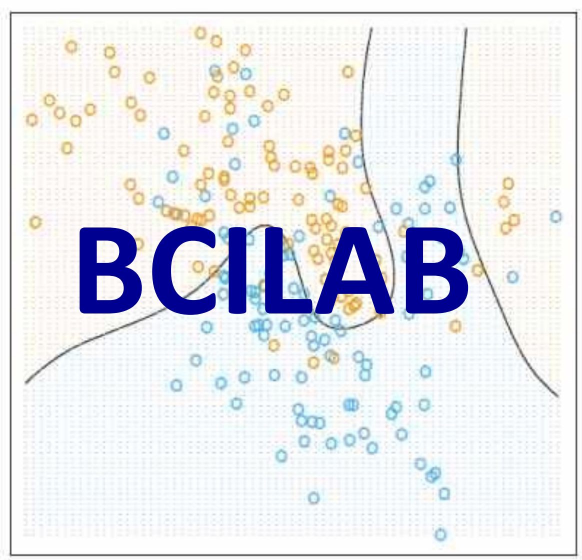


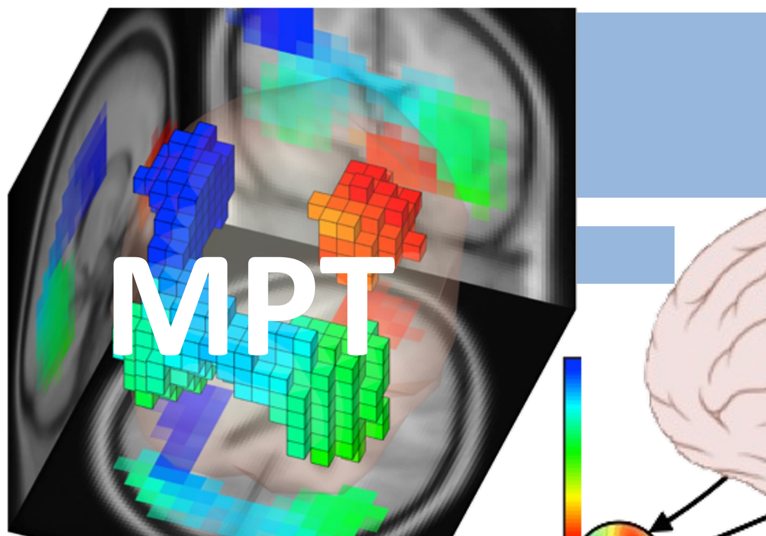
10th Anniversary SCCN Impromptu celebration 1/2/12

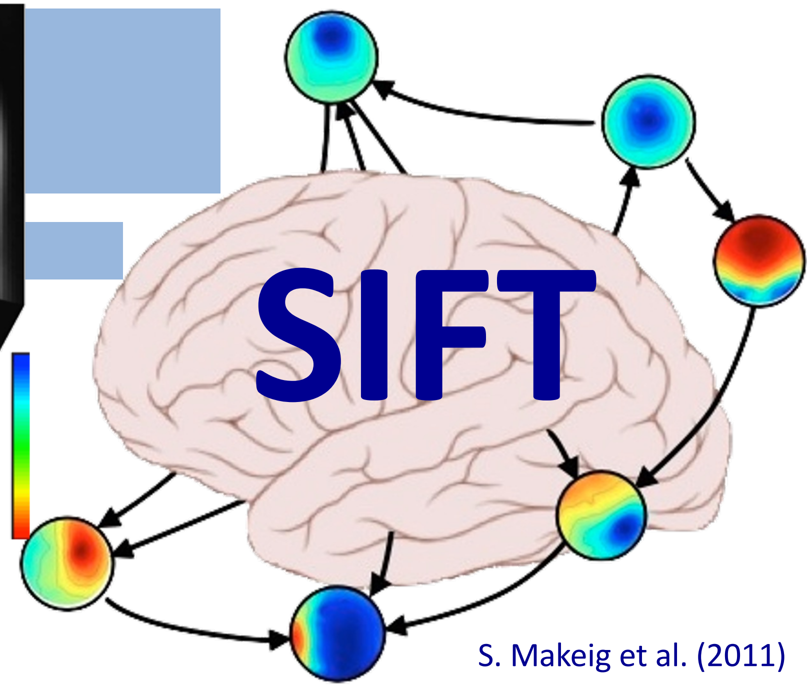












S. Makeig et al. (2011)

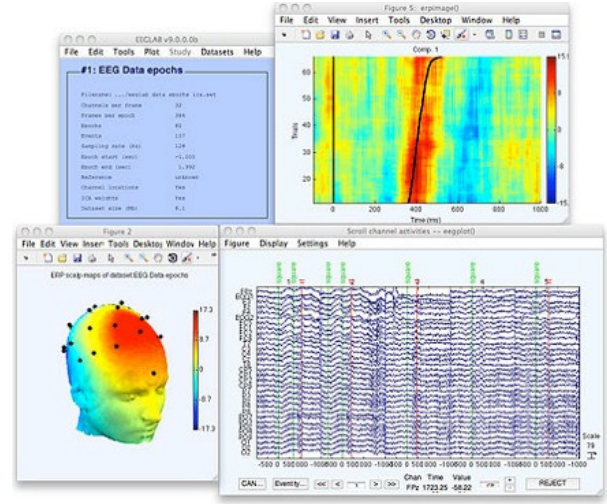
List of data import extensions

EEGLAB EXTENSION MANAGER

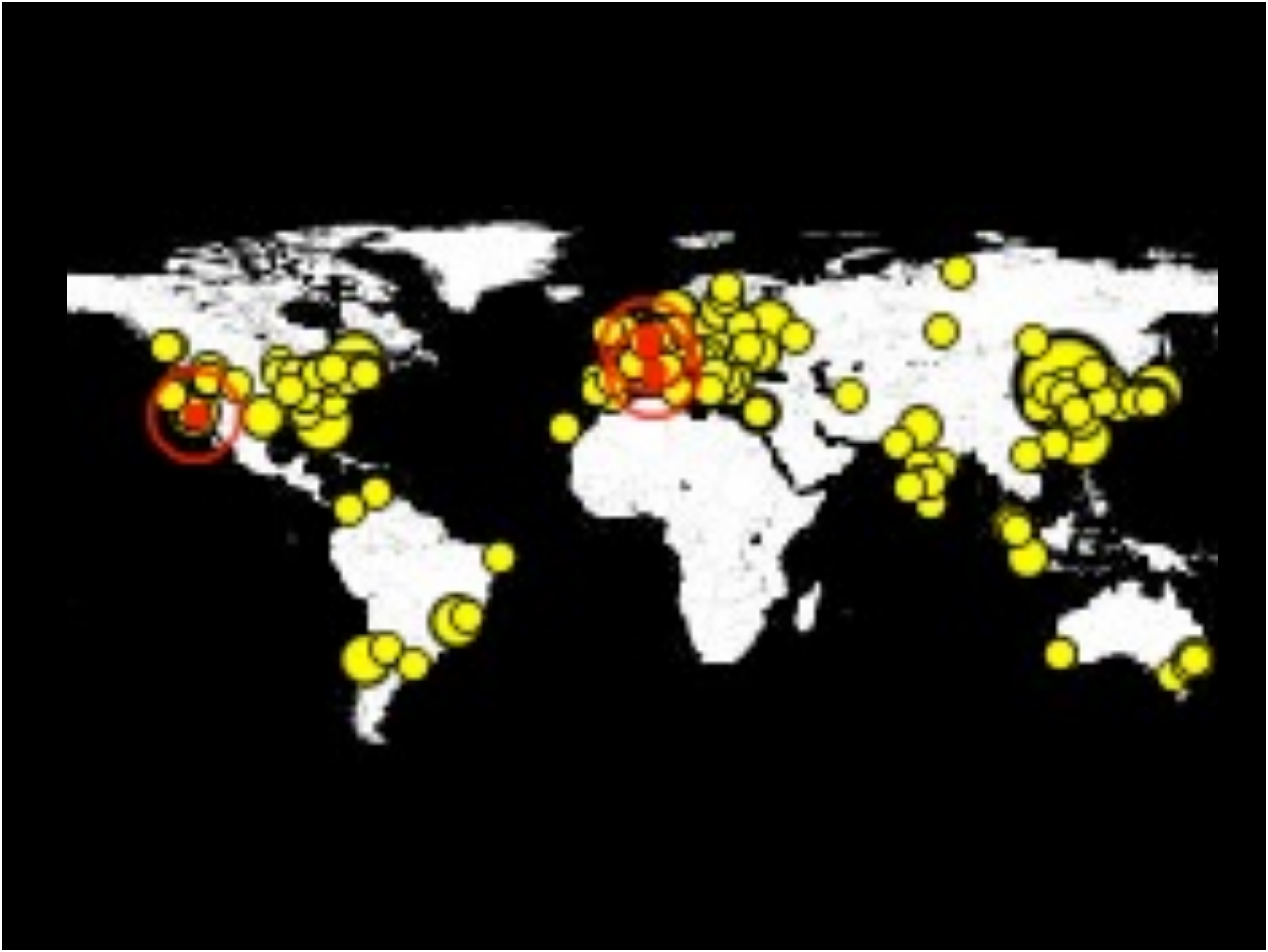
Plug-in name	Version	Short plug-in description	Link	Contact	Comments
MFFimport	1.00	Import MFF files from the EGI company	Download	S. Chennu	User comments
ANTeepimport	1.10	Import ANT .cnt data and trigger files	Download	M. van de Velde	User comments
BCI2000import	0.36	Import BCI2000 data files	Download	C. Boulay	User comments
BDFimport	1.10	Import BDF data files	Download	A. Delorme	User comments
biopac	1.00	Import BIOPAC data files	Download	A. Delorme	User comments
ctfimport	1.04	Import CTF (MEG) data files	Download	D. Weber	User comments
erpssimport	1.01	Import ERPSS data files	Download	A. Delorme	User comments
INSTEPascimport	1.00	Import INSTEP ASCII data files	Download	A. Delorme	User comments
neuroimaging4d	1.00	Import Neuroimaging4d data files	Download	C. Wienbruch	User comments
ProcomInfinity	1.00	Import Procom Infinity data files	Download	A. Delorme	User comments
WearableSensing	1.09	Import Wearable Sensing files	Download	S. Gillen	User comments
NihonKoden	0.10	Import Nihon Koden M00 files (beta)	Download	M. Miyakoshi	User comments
xdfimport	1.12	Import files in XDF format	Download	C. Kothe	User comments
bva-io	1.5.12	Import Brain Vision Analyser data files	Download	A. Widmann	User comments
Fileio	Daily	Import multiple data files formats	Download	R. Oostenveld	User comments
Biosig	2.88	Import multiple data files formats	Download	A. Schloegl	User comments
Cogniscan	1.1	Import Cogniscan data files	Download	P. Sajda	User comments
NeurOne	1.0.3.2	Import NeurOne data files	Download	Support	User comments
loadhdf5	1.0	Load hdf5 files recorded with g.recorder	Download	Simon L. Kappel	User comments

Swartz Center for Computational Neuroscience

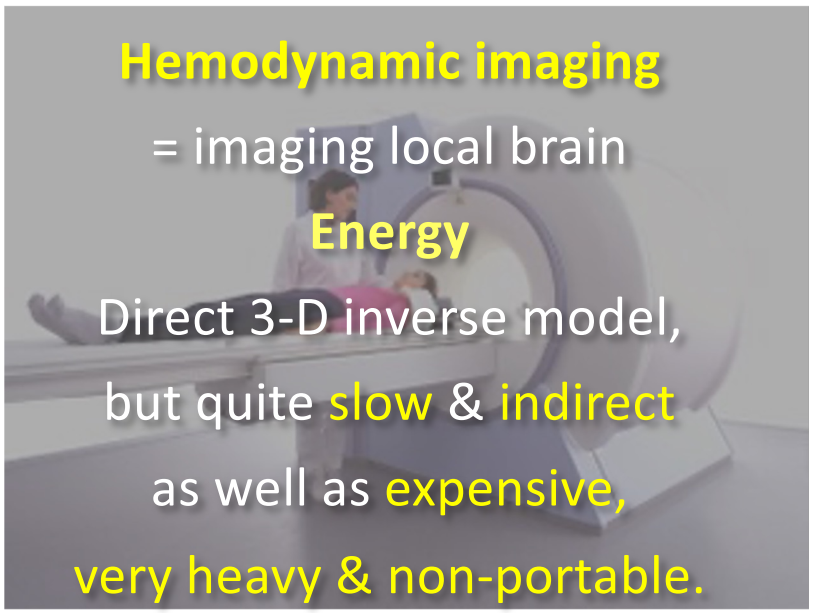
EEGLAB History



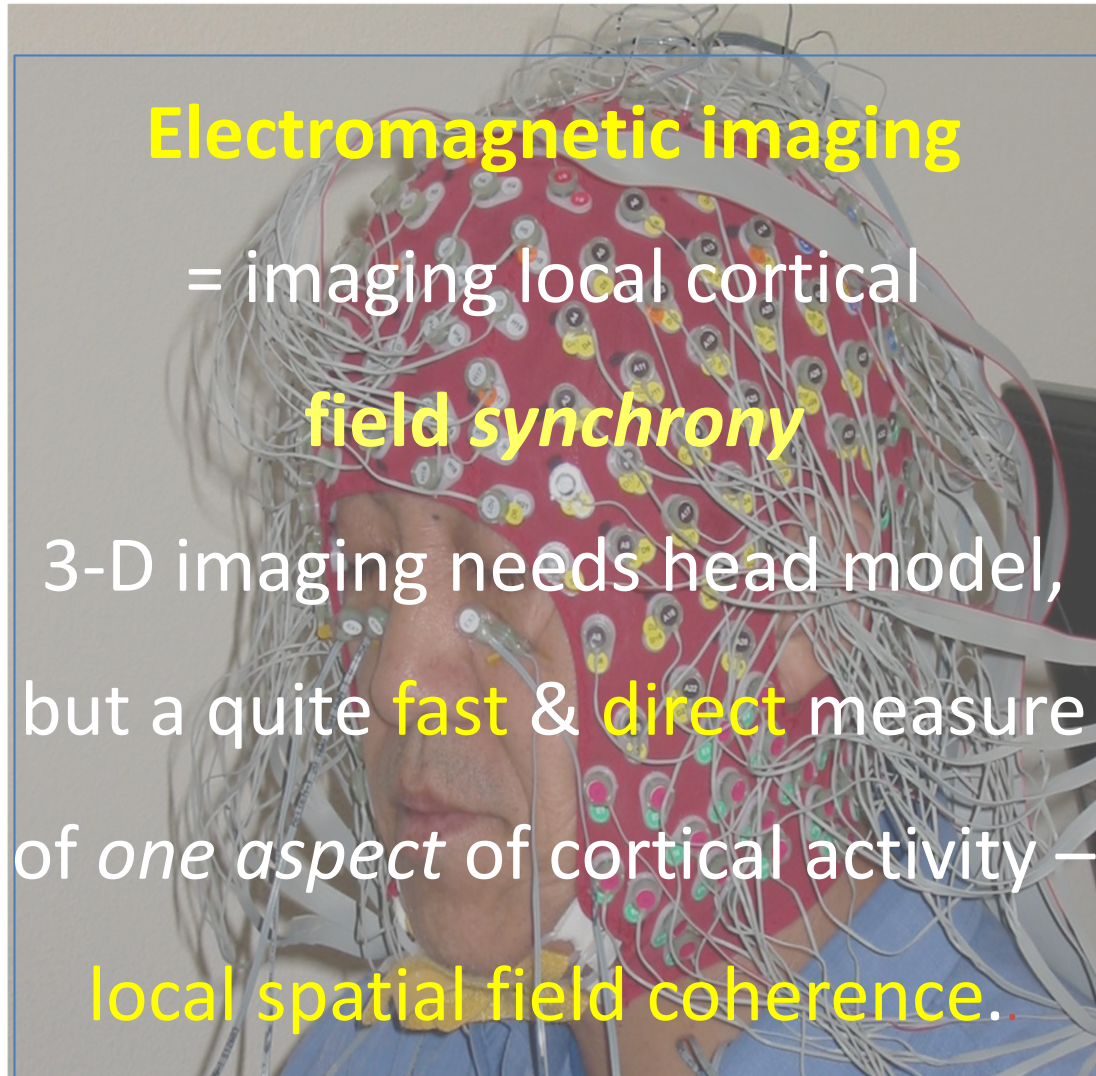
- 1993 – ERSP (Makeig)
- 1995 – Infomax ICA for EEG (Makeig, Bell, Jung, Sejnowski)
- **1997 - EEG/ICA Toolbox (cnl.salk.edu), ITC & ERC**
- 1999 - ERP-image plotting (Jung & Makeig)
- 2000 – **EEGLAB GUI design (Delorme)**
- **2002 – 1st EEGLAB (sccn.ucsd.edu)**
- **2004 - 1st EEGLAB support from U.S. NIH and reference paper (Delorme & Makeig, 2004)**
- **2006 - 1st EEGLAB plug-ins, STUDY structure, and component clustering tools**
- **2009+ – New toolboxes: NFT, SIFT, BCILAB, MPT, … (Akalin Acar, Mullen, Kothe, …)**
- **2011 – EEGLAB, the most widely used EEG research environment (Henke & Halchenko)**
- **2013 – Lab Streaming Layer (LSL) (Kothe) for Mobile Brain/Body Imaging (MoBI) (Makeig)**
- **2013 – *HeadIT.org* online, HED/ESS neuroinformatic tools (Bigdely-Shamlo)**
- **2017 – LIMO / GLM integrated (Pernet) -- and 24rd- 26th EEGLAB Workshops …**
- **2018 – The Open EEGLAB Portal via the Neuroscience Gateway (nsgportal.org).**
- **2019 – EEGLAB 2019, BIDS integration, ICLabel, get_chanlocs, etc.**



Functional Brain Imaging



1993 -



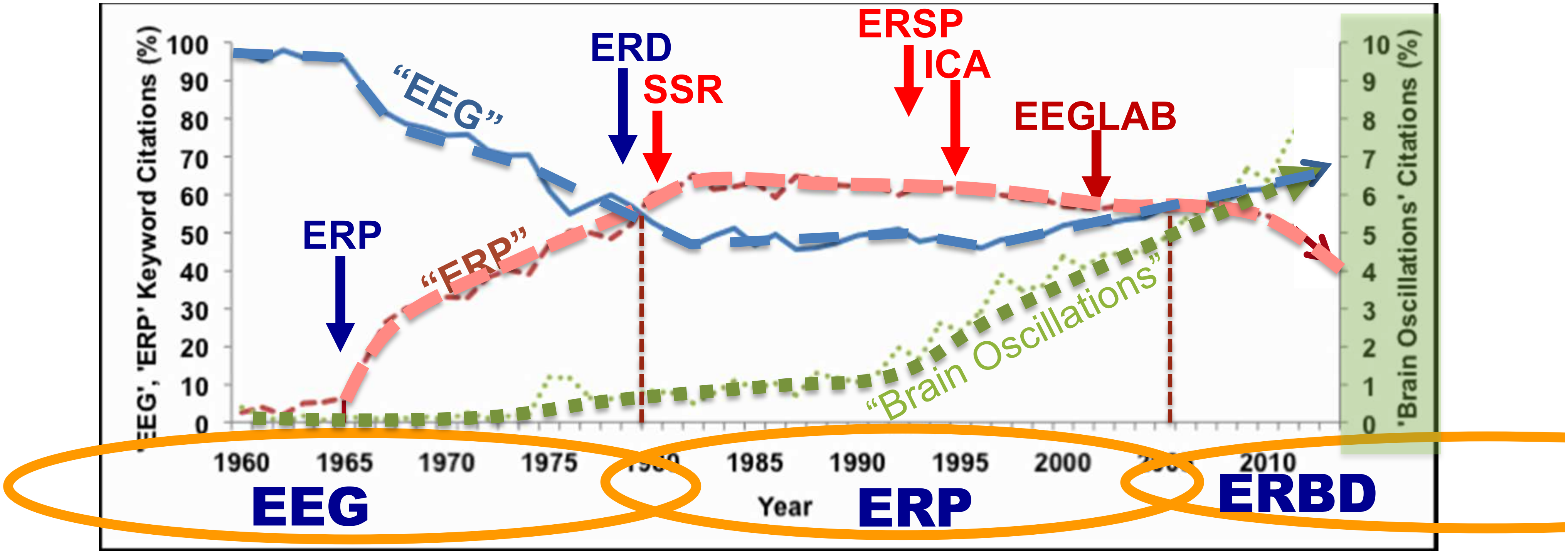
1926 -

S. Makeig 2018

Functional Brain Imaging using EEG

- EEG imaging is noninvasive → little ethical concern
- EEG imaging can be tolerated by most subjects
- EEG imaging has fine time resolution
- EEG imaging is lightweight / mobile / wearable
- EEG imaging is inexpensive → scalable
- EEG source imaging requires a *good* forward-problem electrical head model and inverse localization method.
- Historically, much inertia in EEG methods development

Three Modern Eras of EEG Research



Loo, Lenartowicz & Makeig, 2015

Figure 1. Relative number of PubMed citations retrieved by 'All Fields' search terms: 'EEG,' 'ERP,' and 'Brain Oscillations.' The percent of citations for each search term relative to the total number of citations returned by a search for any of the three terms is plotted relative to the other two search terms. For visual clarity, 'Brain Oscillations' citations are graphed with a green dotted line according to the Y-axis labels on the right; 'EEG' with a blue solid line and 'ERP' with a red dashed line according to the Y-axis labels on the left.

S. Makeig, 2016

Three Aspects of Human Consciousness

Knowing - I perceive, remember, believe

Feeling - I feel, experience as feeling

Willing - I act, aim, intend

"[Humans] have *full consciousness* of the [physical] world
in **all the aspects of knowing, feeling and willing**."

Meher Baba

S. Makeig (2017)

EEG & Cognitive Neuroscience

EEG can be used to learn and monitor
how the brain and nervous system
supports human consciousness
in all its aspects --

Knowing

Feeling

Willing

S. Makeig (2017)

Embodied Agency

Brain processes

have evolved and function

to optimize the outcomes

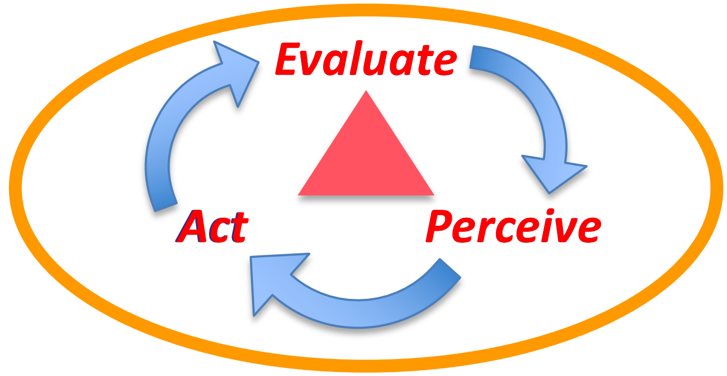
of the ***willed*** *behavior*

the brain organizes

in response to

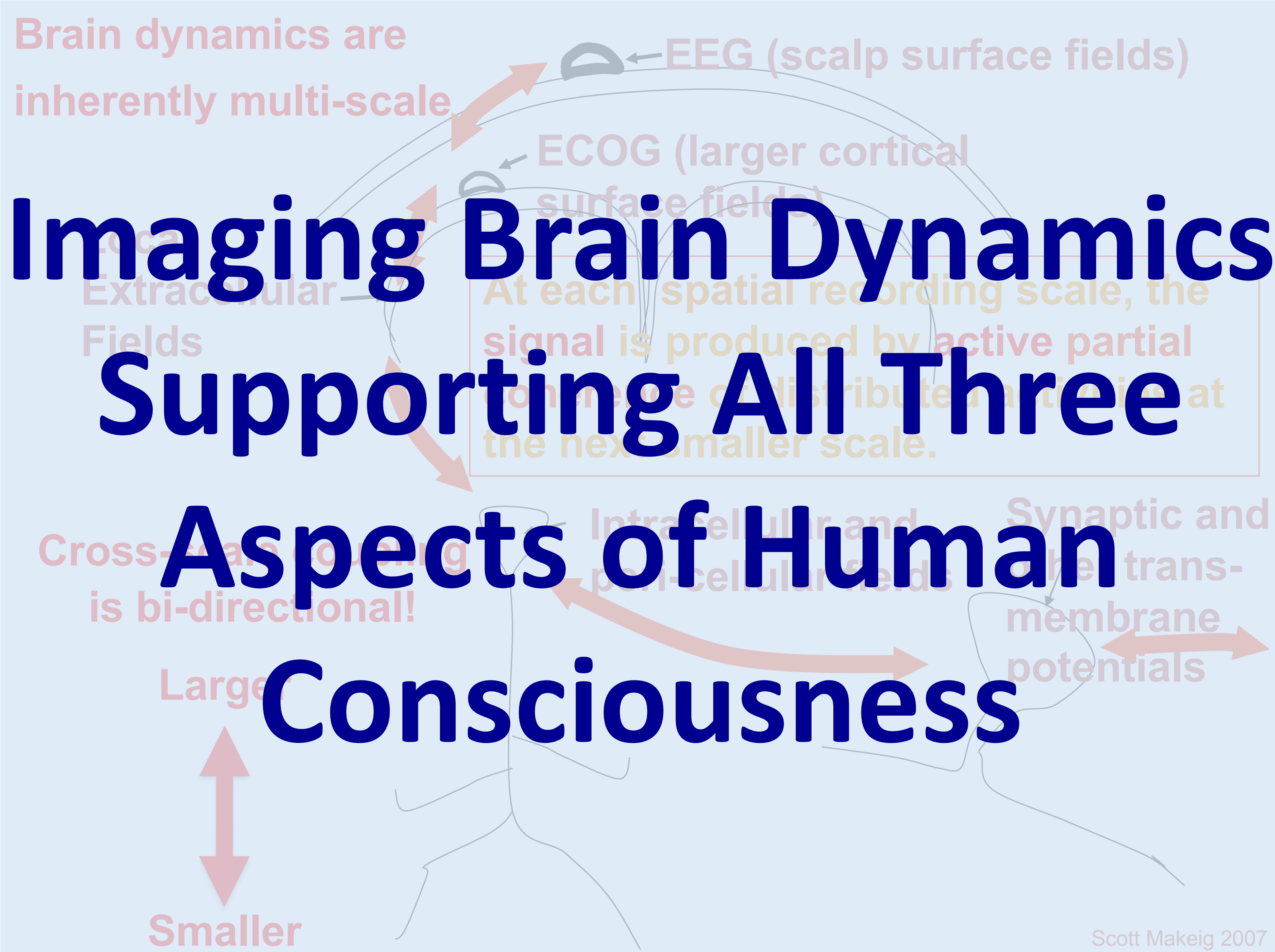
perceived & felt

challenges and opportunities.



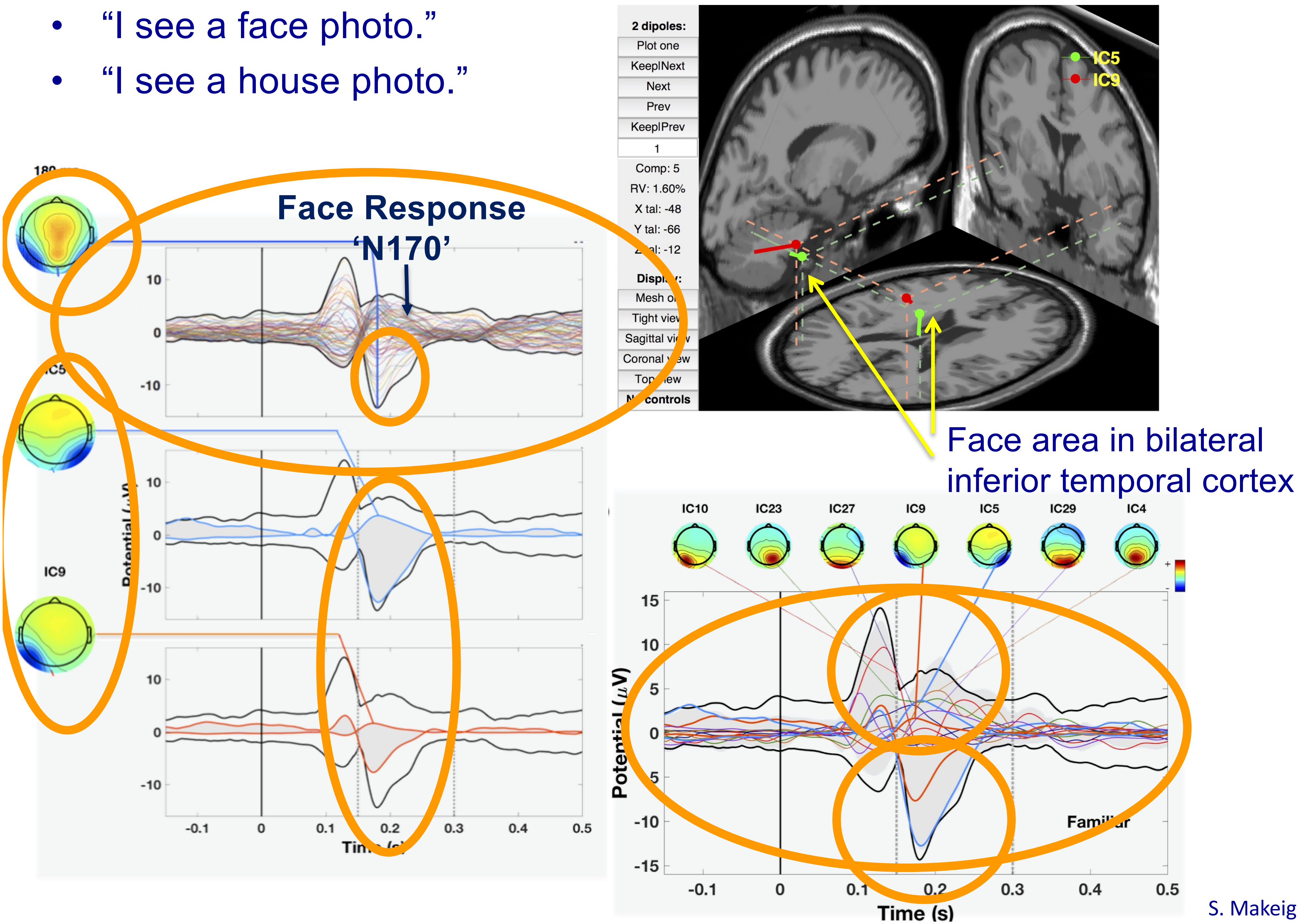
Brains meet the challenge
of the moment
– *every* moment!

Imaging Brain Dynamics Supporting All Three Aspects of Human Consciousness



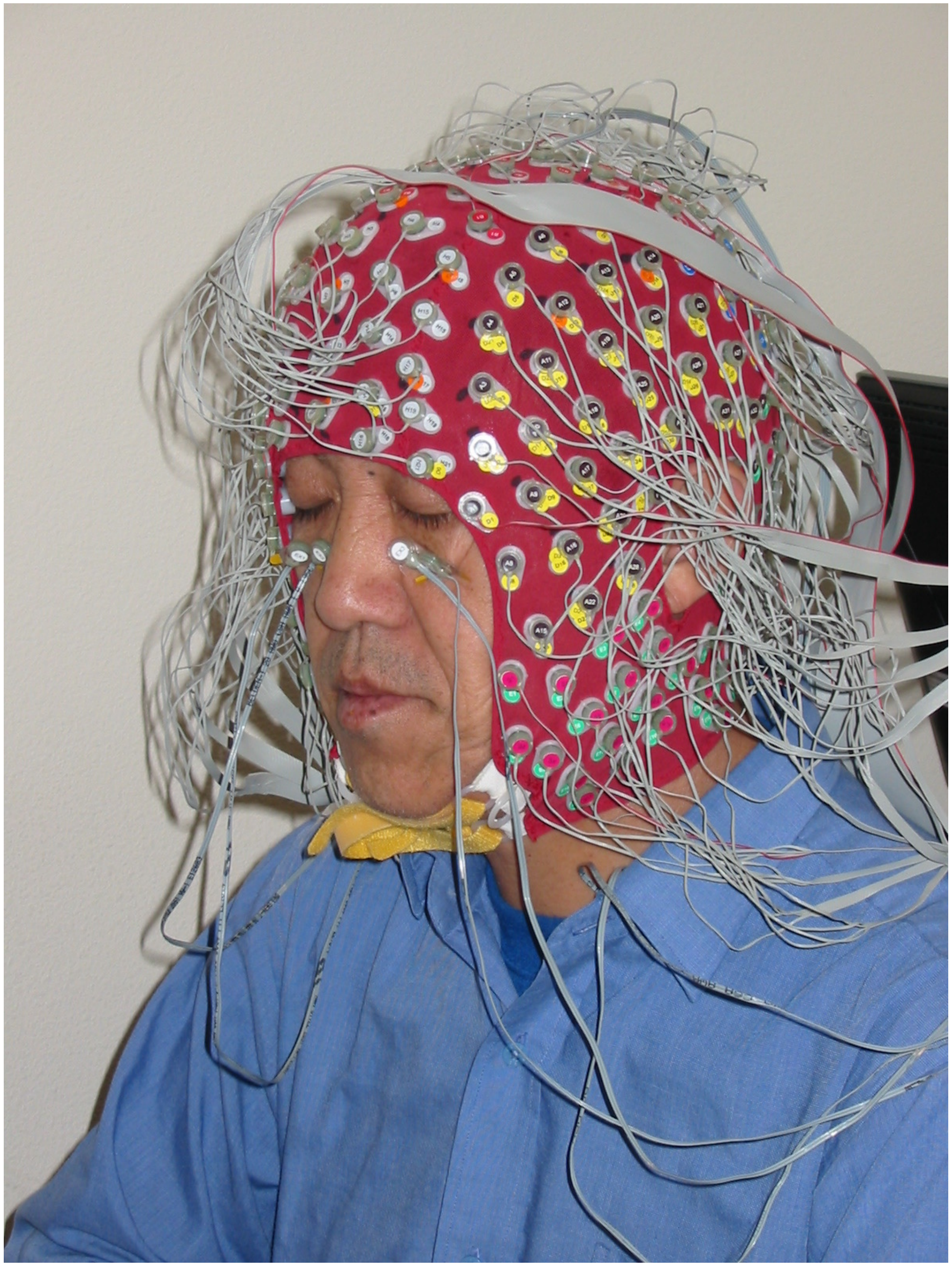
Knowing

- "I see a face photo."
- "I see a house photo."



S. Makeig (2017)

Feeling



Emotion Imagination Experiment

Suggested the eyes-closed experience of 15 different emotions *via guided imagery*.

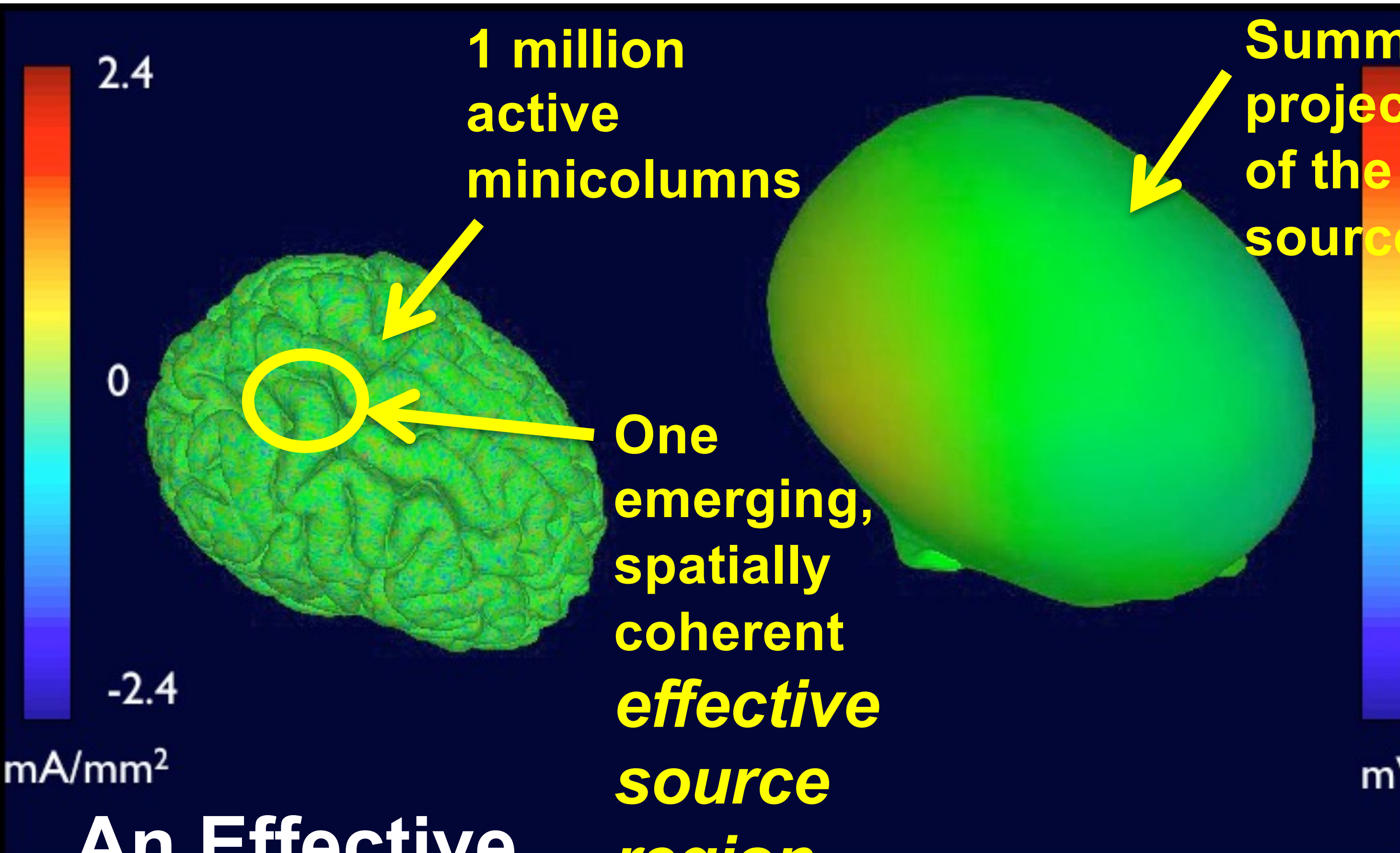
Collected 1-5 min of continuous high-density EEG data in each emotion state.

28 subjects

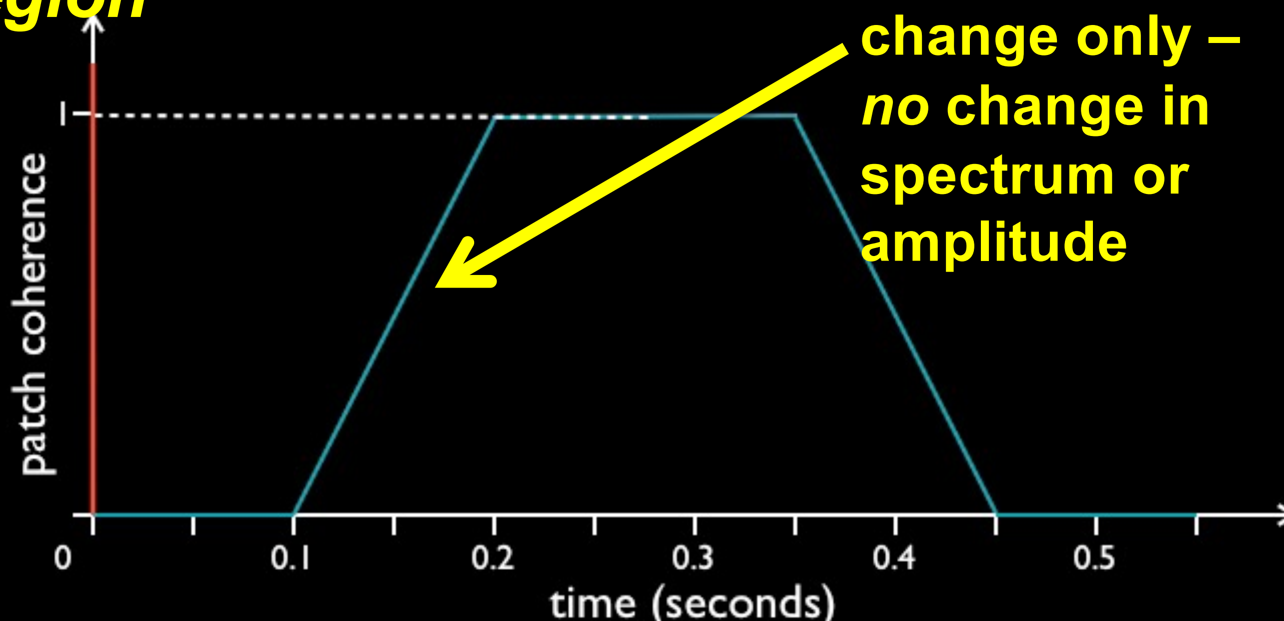
Onton & Makeig, 2009

Willing

Imaging Human Agency

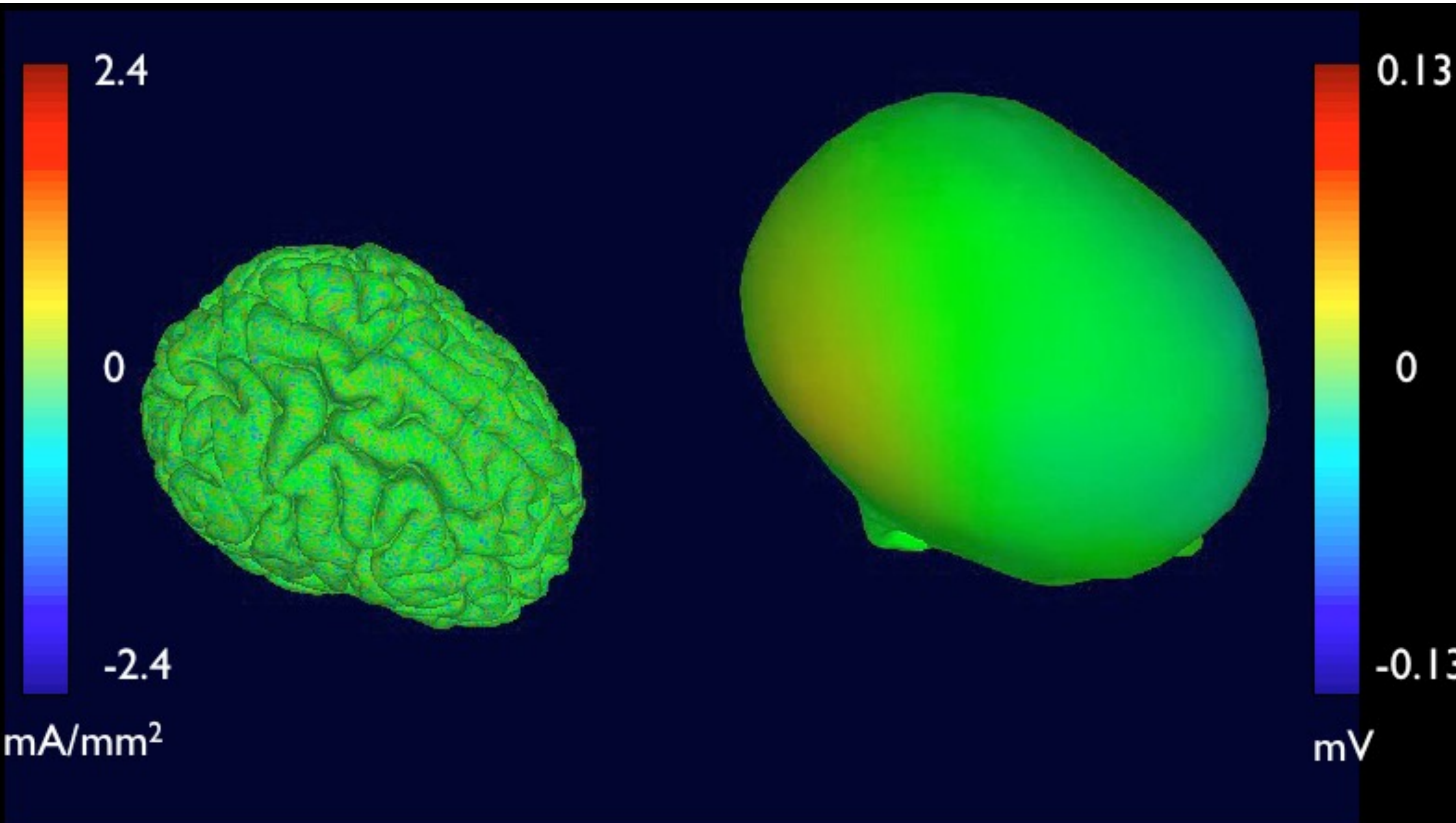


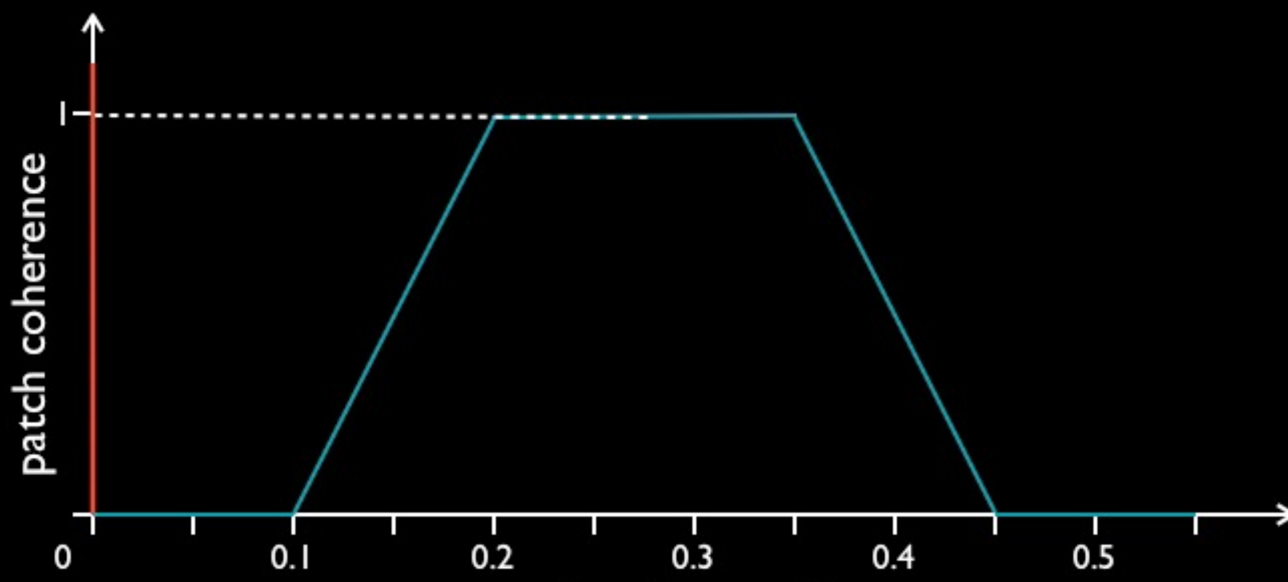
An Effective EEG Source



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

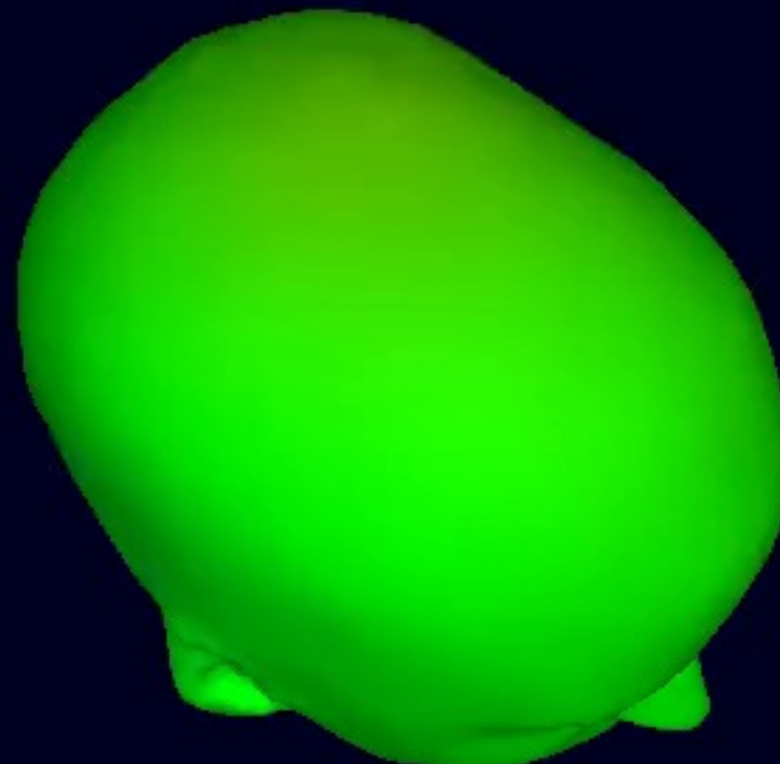
Z. Akalin Acar & S. Makeig (2015)





Z. Akalin Acar & S. Makeig (2015)

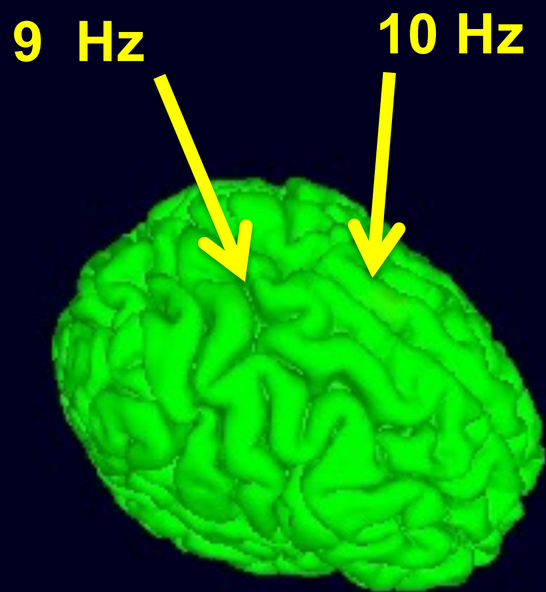
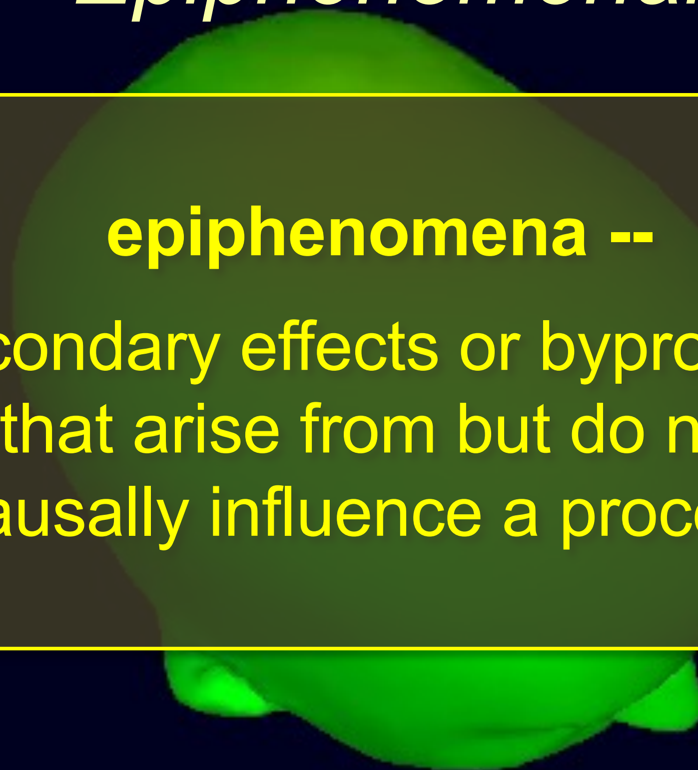
Here, what are the cortical ‘effective sources’?



Scalp projection

Z. Akalin Acar & S. Makeig (2012)

Scalp epiphenomena !

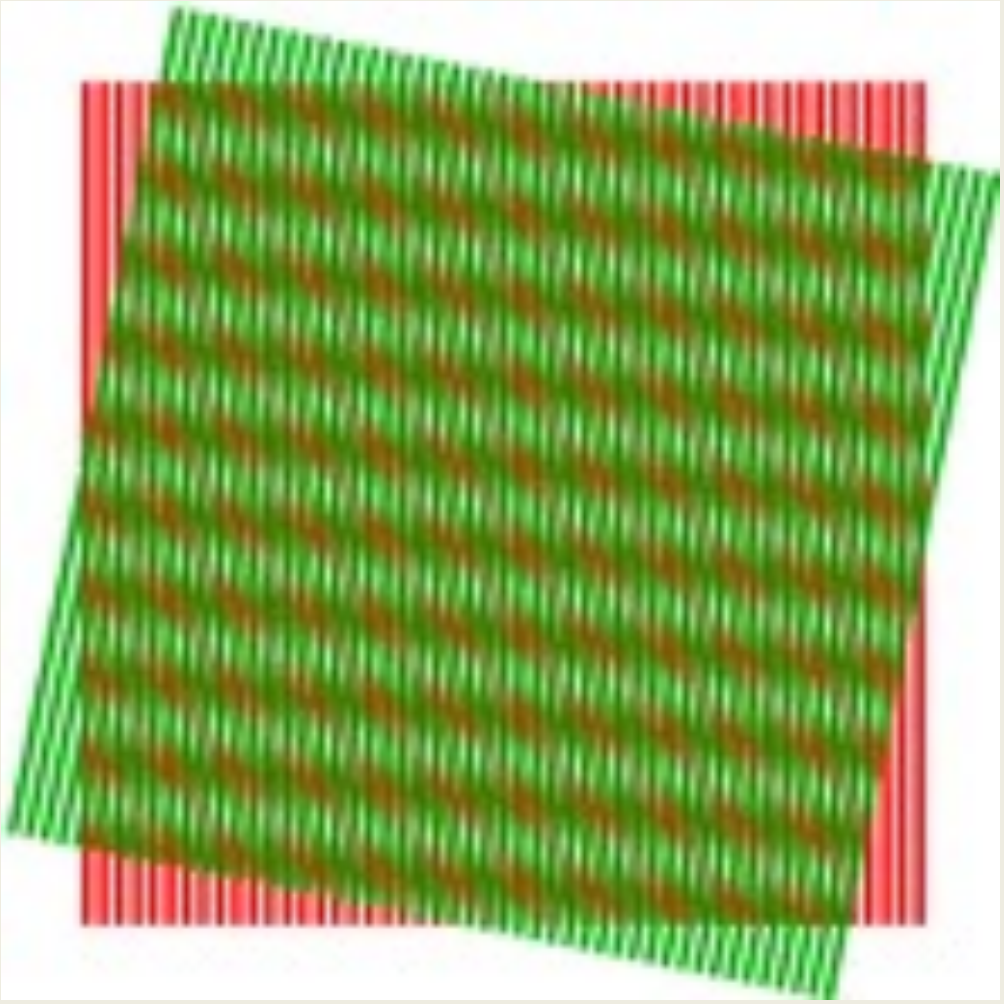
Phenomena	*Epiphenomenal*
	
Two spatially stationary cortical effective sources	**Summed scalp projection**

epiphenomena --

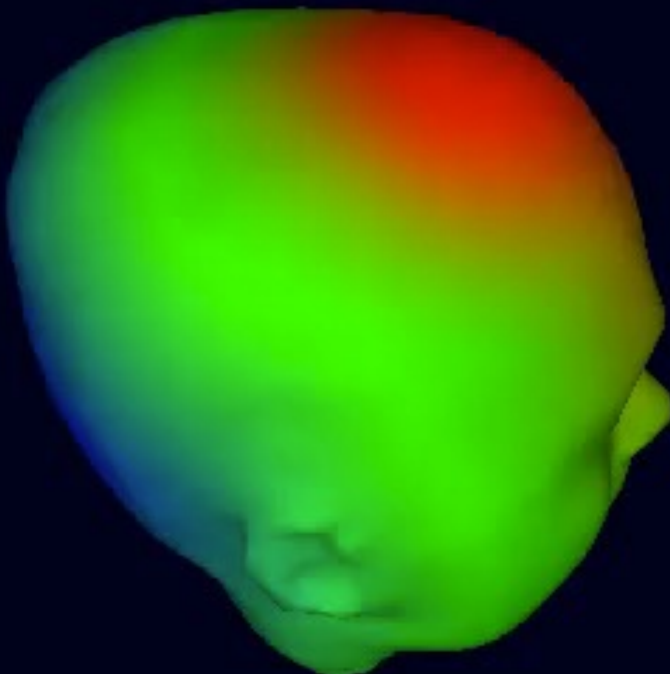
secondary effects or byproducts that arise from but do not causally influence a process.

Z. Akalin Acar & S. Makeig (2012)

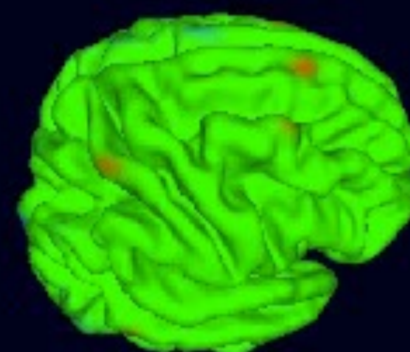
Moire pattern



Summed scalp projections of 13 effective brain sources

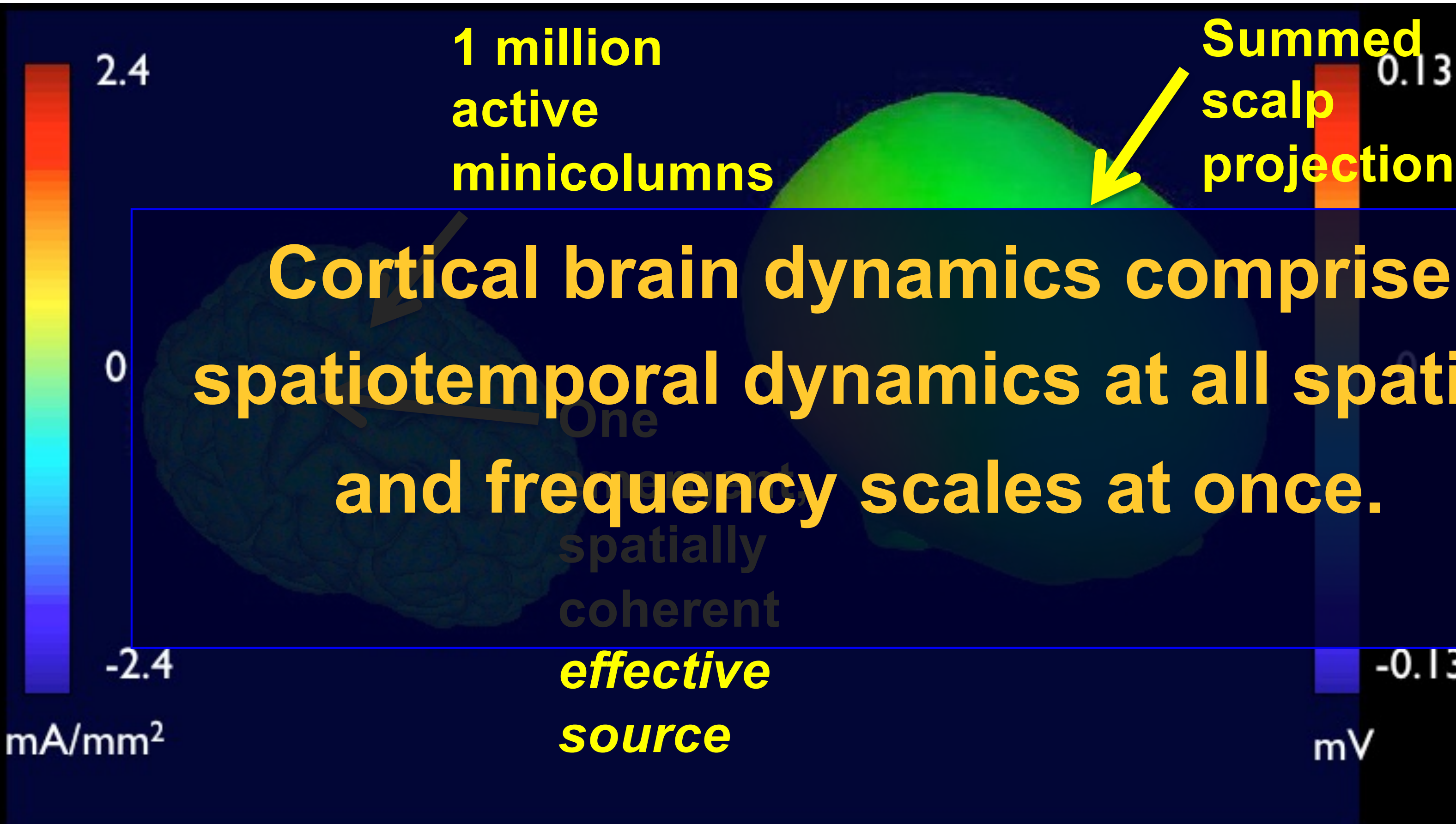


Epiphenomenal Impressions



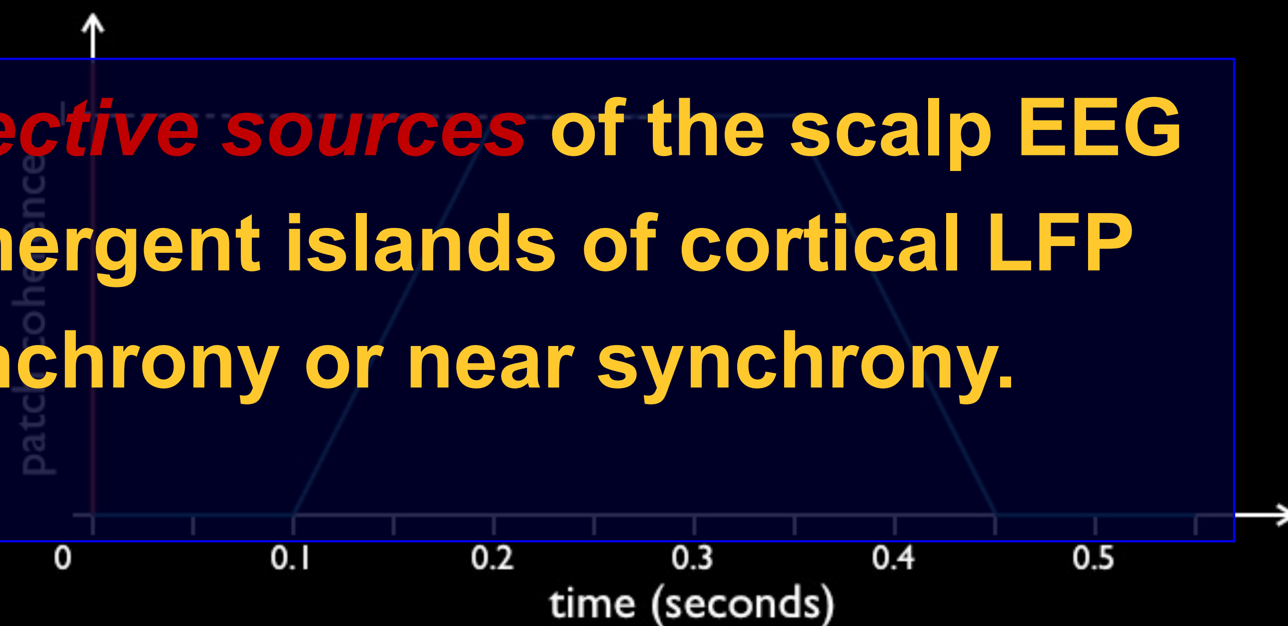
Causal Phenomena

Z. Akalin Acar & S. Makeig (2016)



Cortical brain dynamics comprise spatiotemporal dynamics at all spatial and frequency scales at once.

The *effective sources* of the scalp EEG are emergent islands of cortical LFP synchrony or near synchrony.

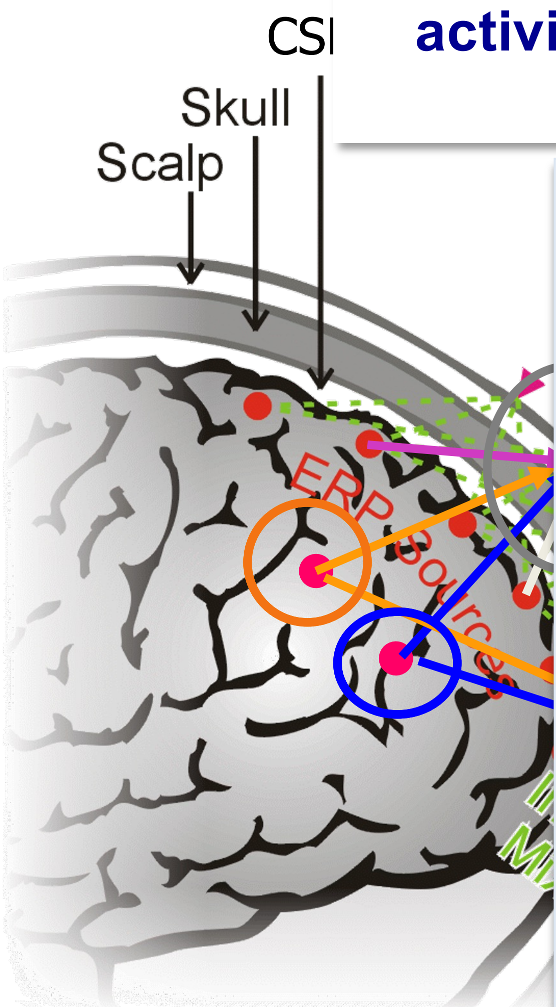


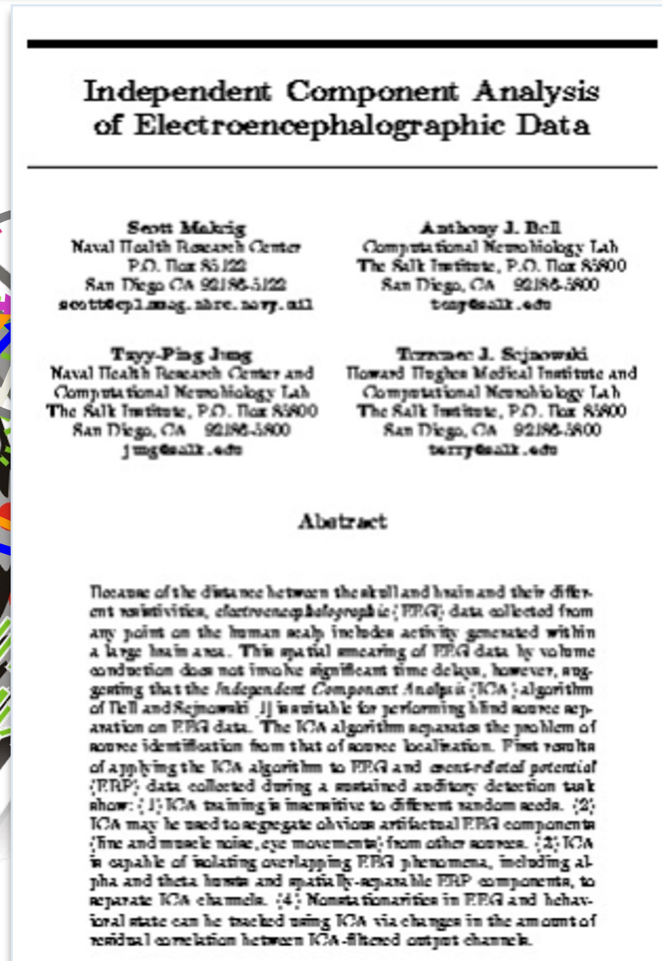
Z. Akalin Acar & S. Makeig (2015)

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

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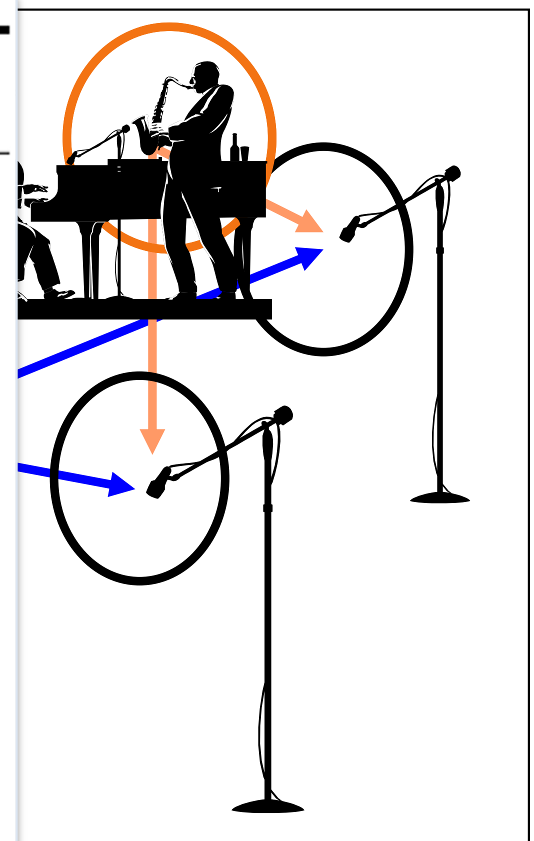
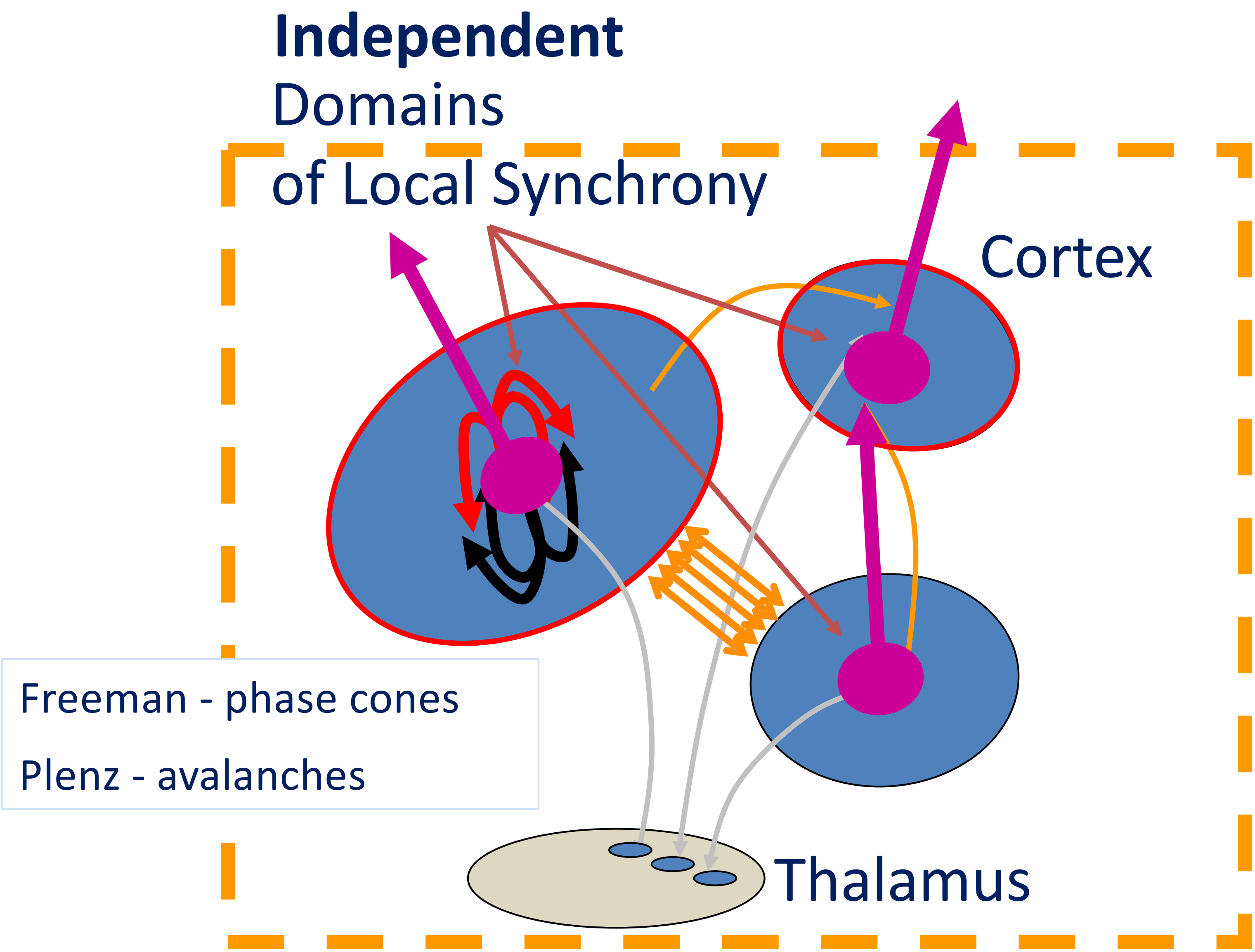
Abstract

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.



S. Makeig, S. Enghoff (2000)

Are EEG effective source signals independent?



S. Makeig (2007)

The EEG Inverse Problem is Twofold

Effective source

Identification → Localization

ICA gives a model-based response to the first question:

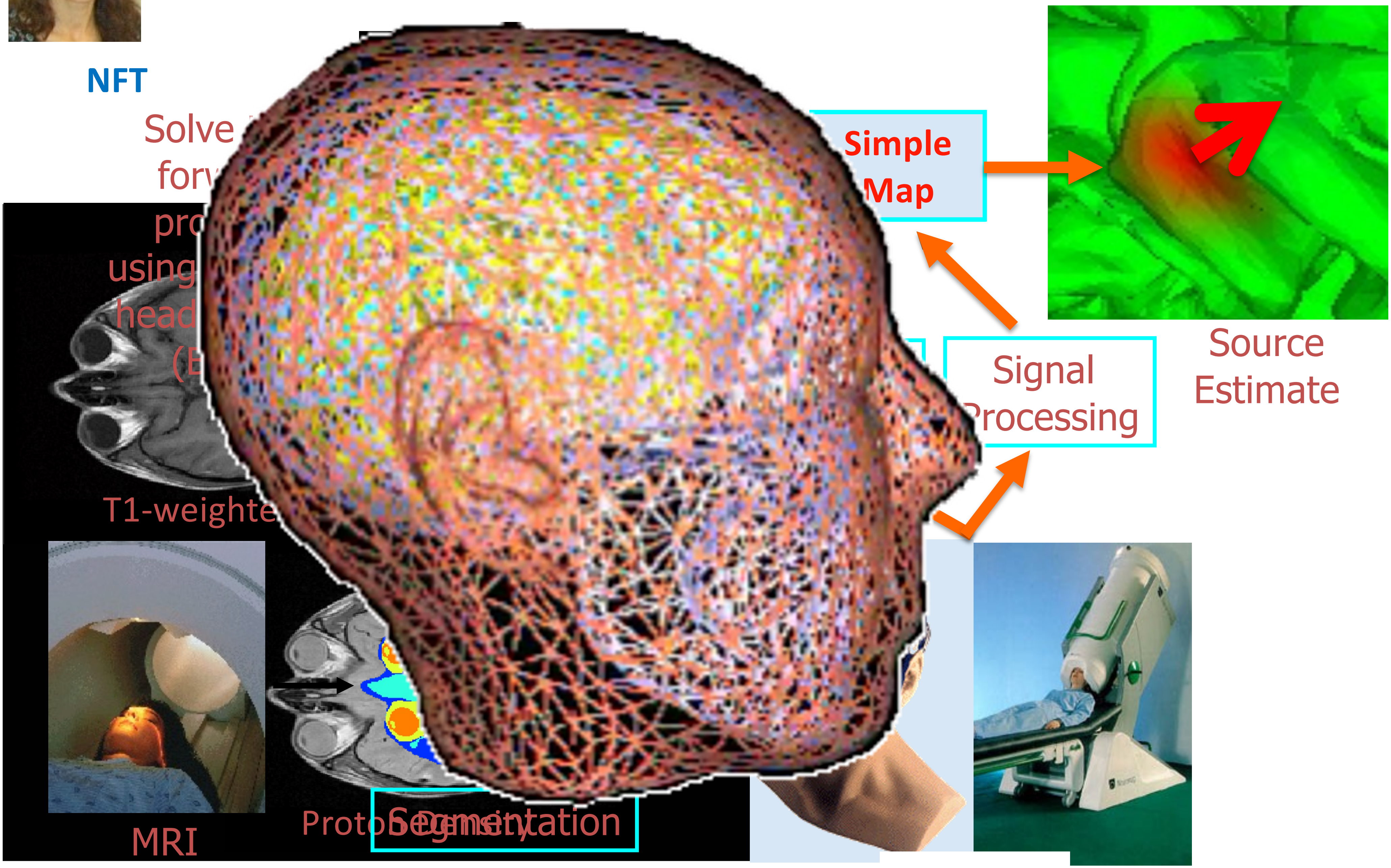
- ***What* are the effective sources? (identification)**

And it greatly helps answer the second question:

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

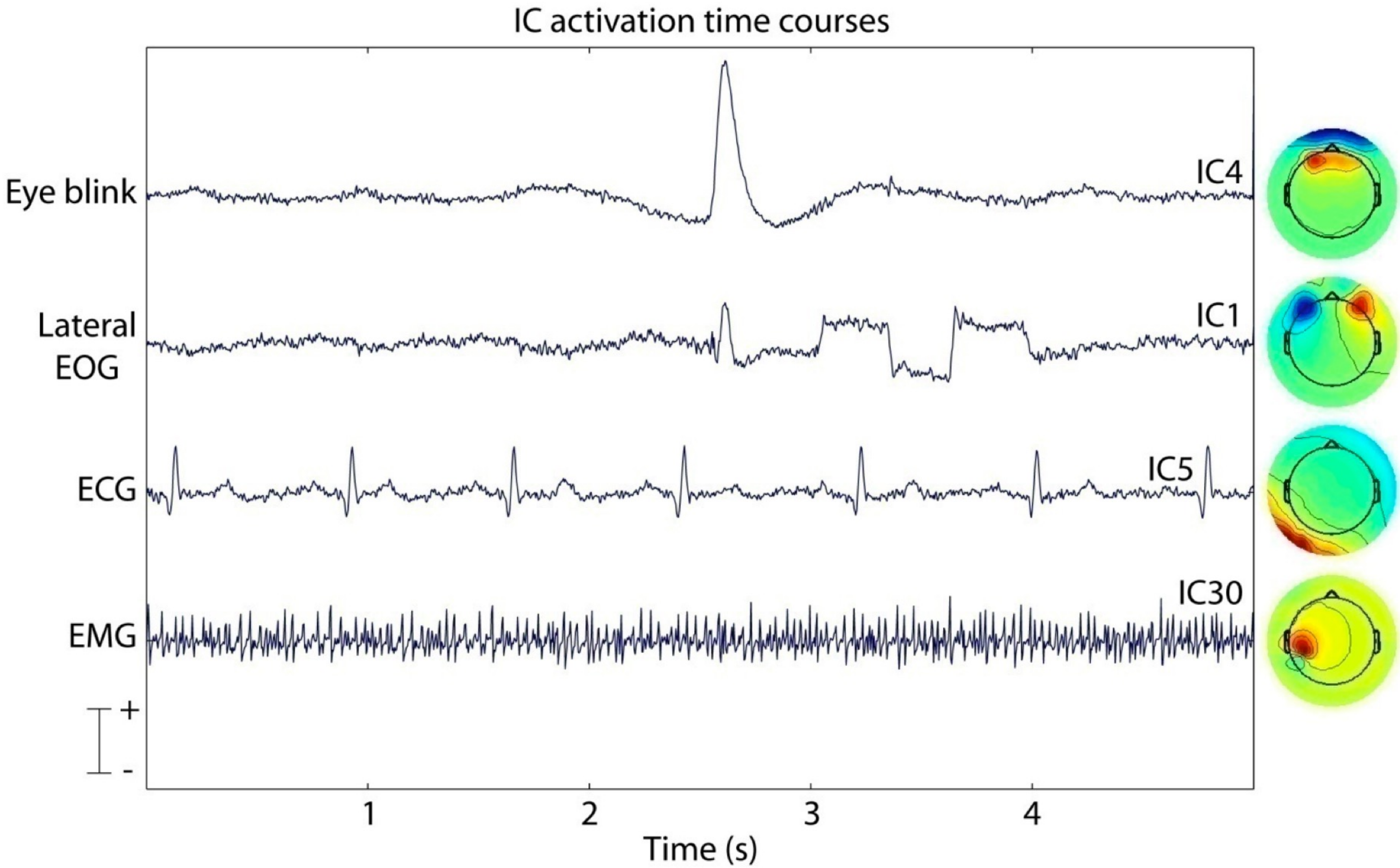
Tchoe et al., *Science Translat. Med.,* 2022

Electromagnetic source localization using realistic head models



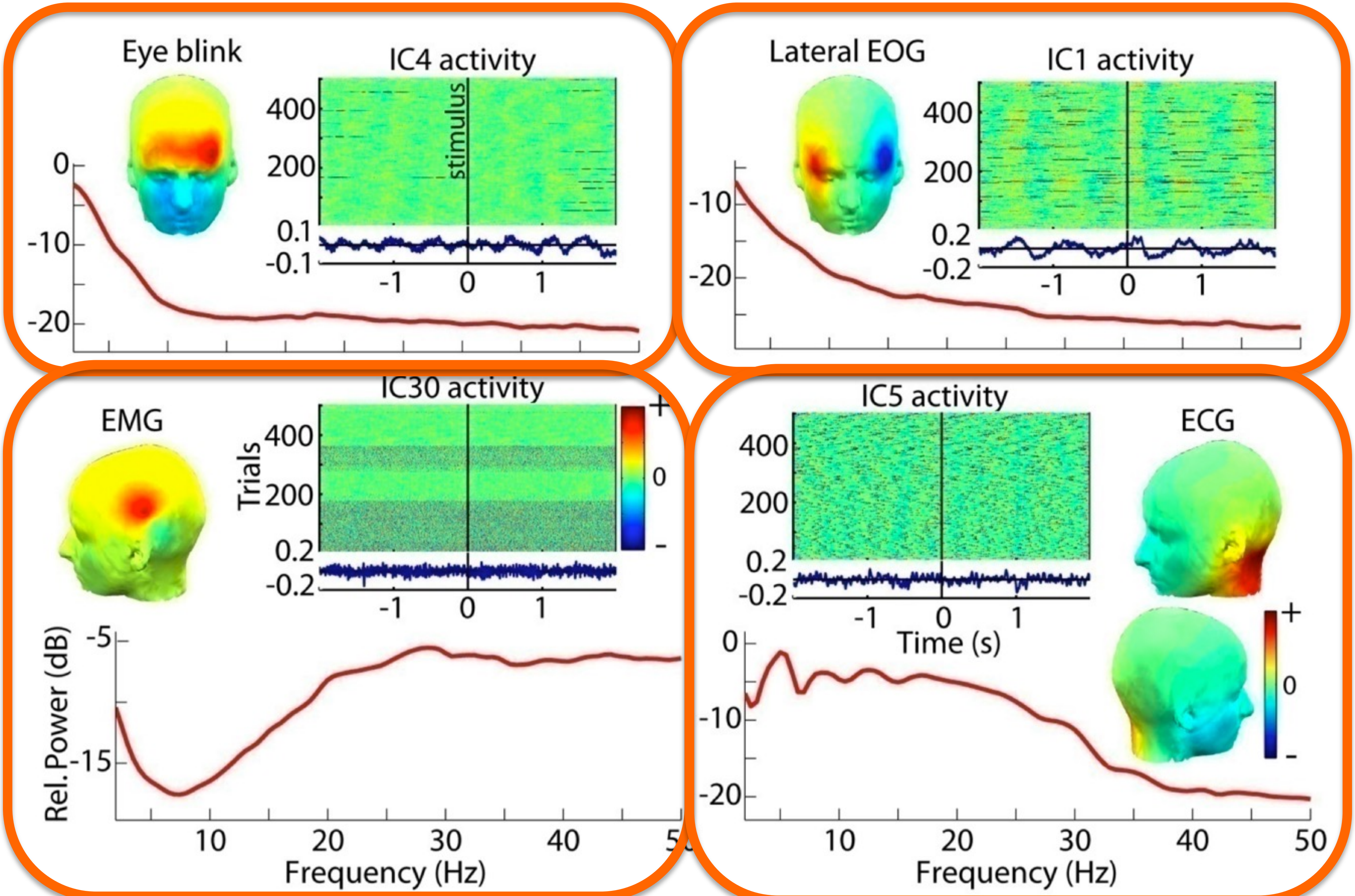
Zeynep Akalin Acar & Scott Makeig '06

ICA separates *non-brain* effective source processes



J. Onton & S. Makeig 2006

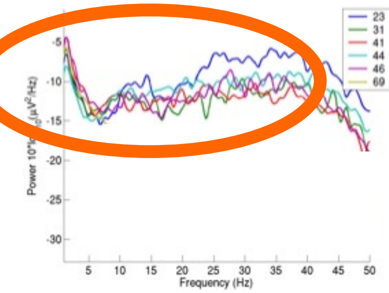
ICA finds non-brain independent component (IC) processes …

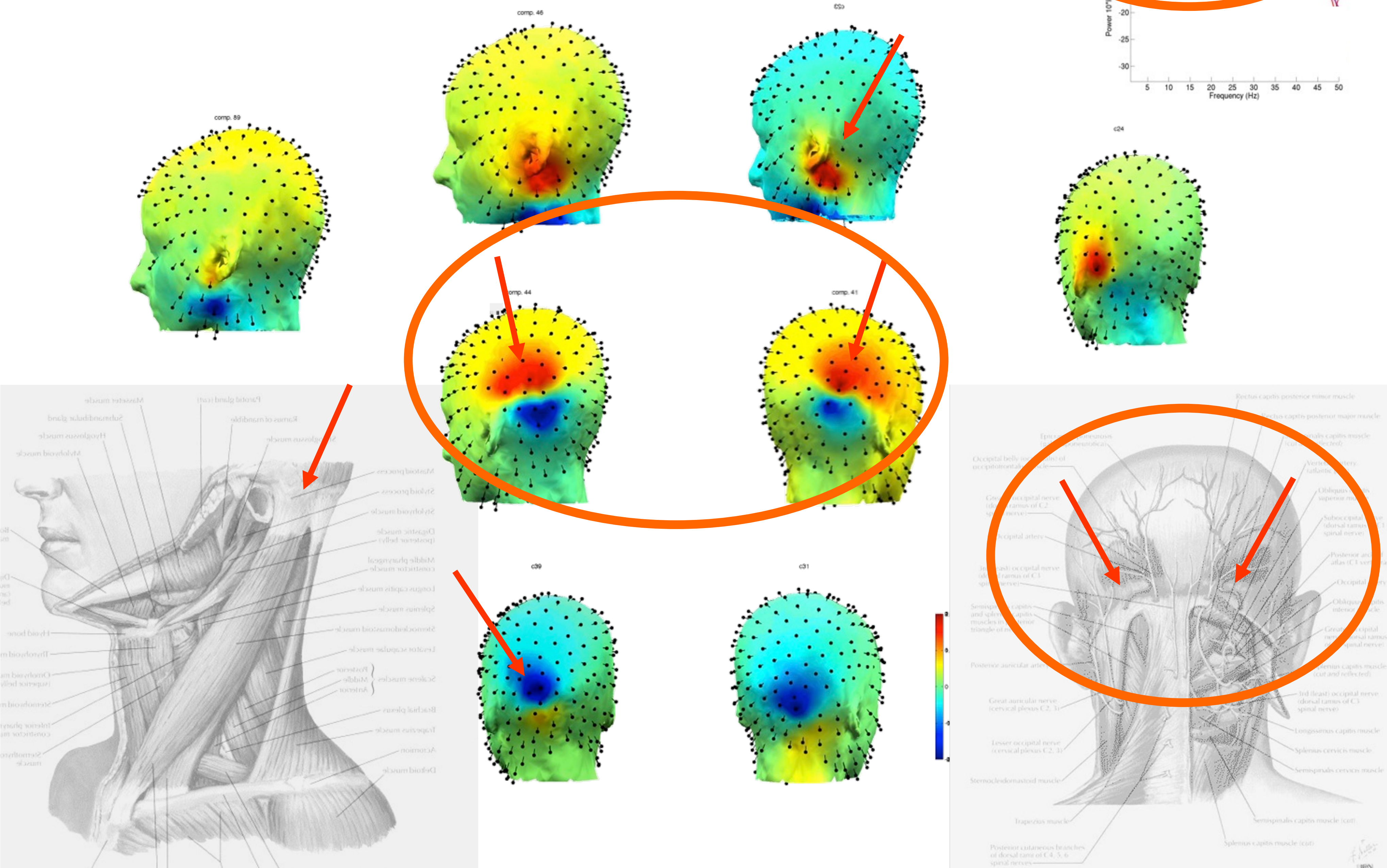


… separates them from the remainder of the data …

J. Onton & S. Makeig 2006

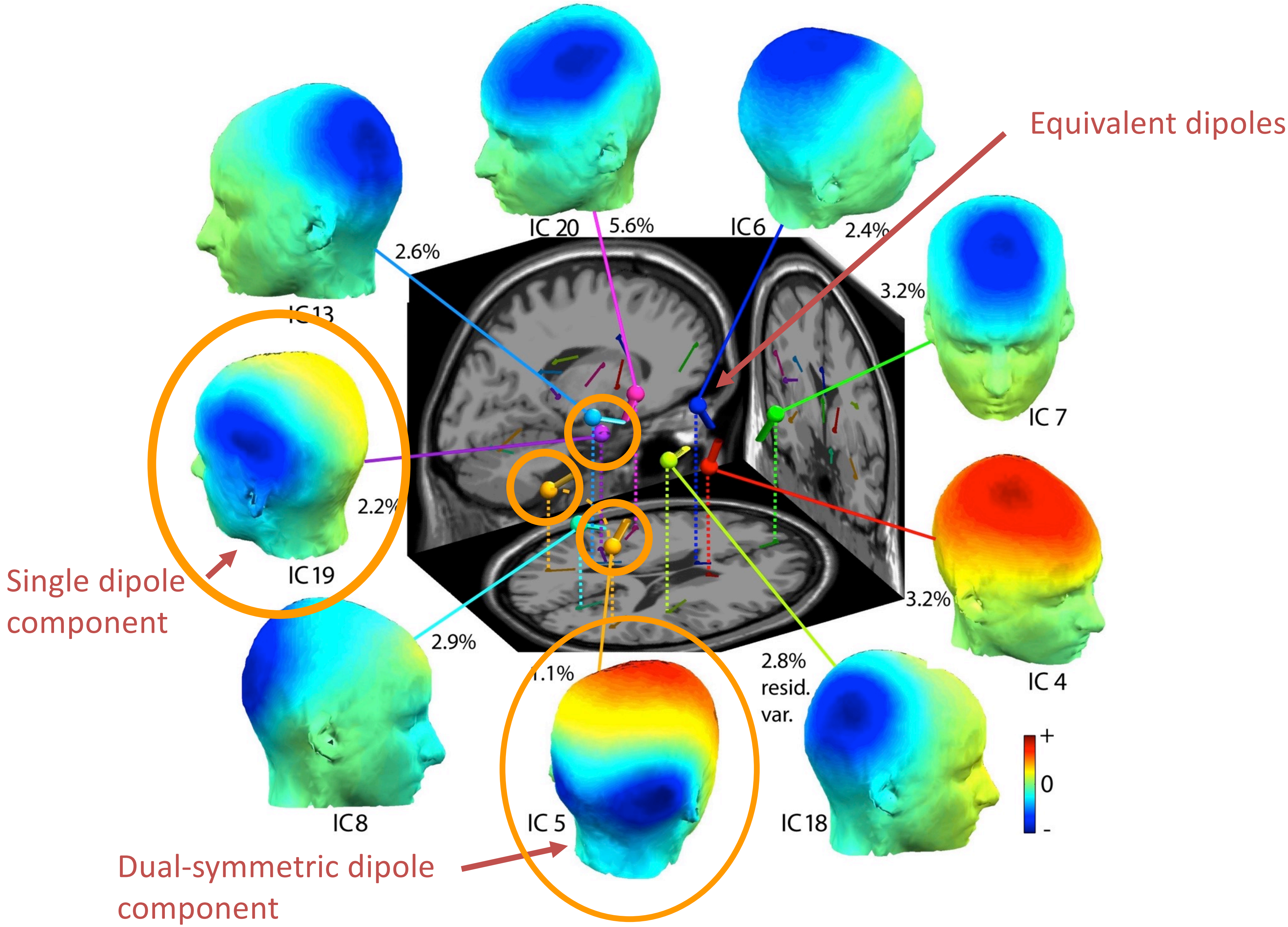
… including IC EMG sources





S. Makeig, J. Onton 2005

… and *also* separates cortical *brain* IC processes



Julie Onton & S. Makeig (2006)

ICLabel: A crowd-sourced AI independent component classifier

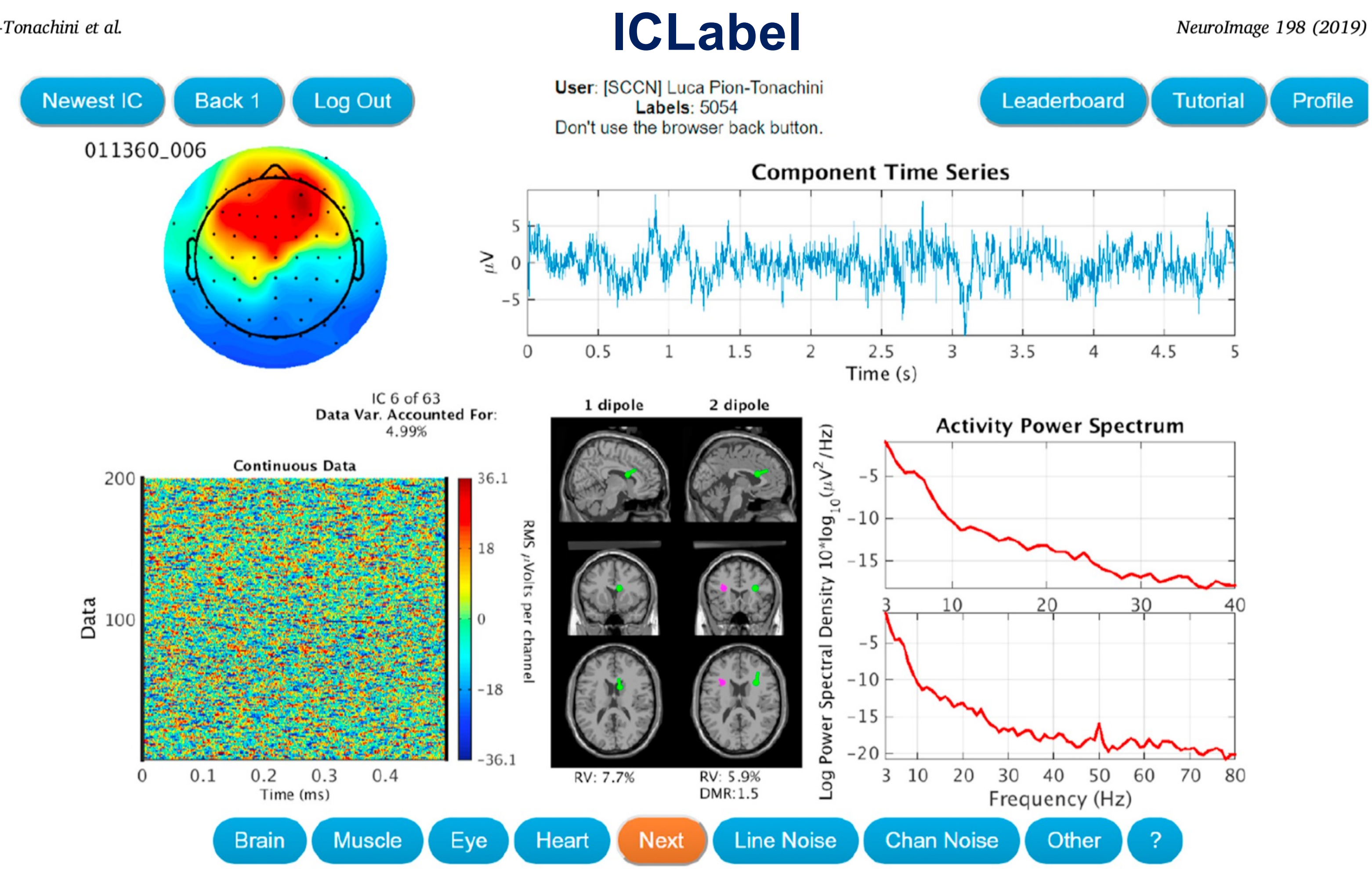
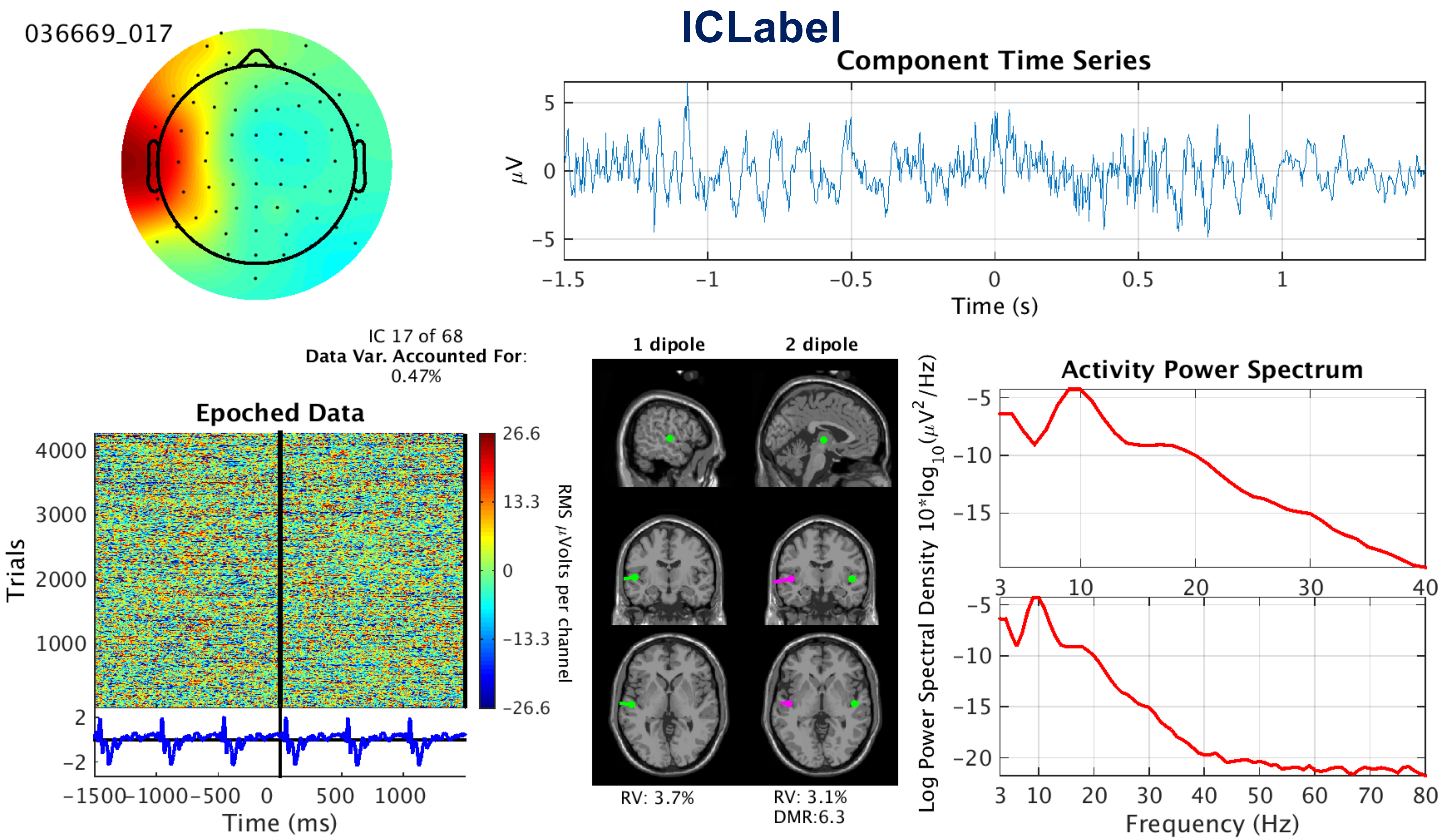


Fig. 1. An IC labeling example from the ICLabel website (https://iclabel.ucsd.edu/tutorial), which also gives a detailed description of the features shown above. Label contributors are shown the illustrated IC measures and must decide which IC category or categories best apply. They mark their decision by clicking on the blue buttons below, and have the option of selecting multiple categories in the case that they cannot decide on one or believe the IC contains an additive mixture of sources. There is also a "?" button that they can use to indicate low confidence in the submitted label.

labeling.ucsd.edu/tutorial

Luca Pion-Tonachini, 2019

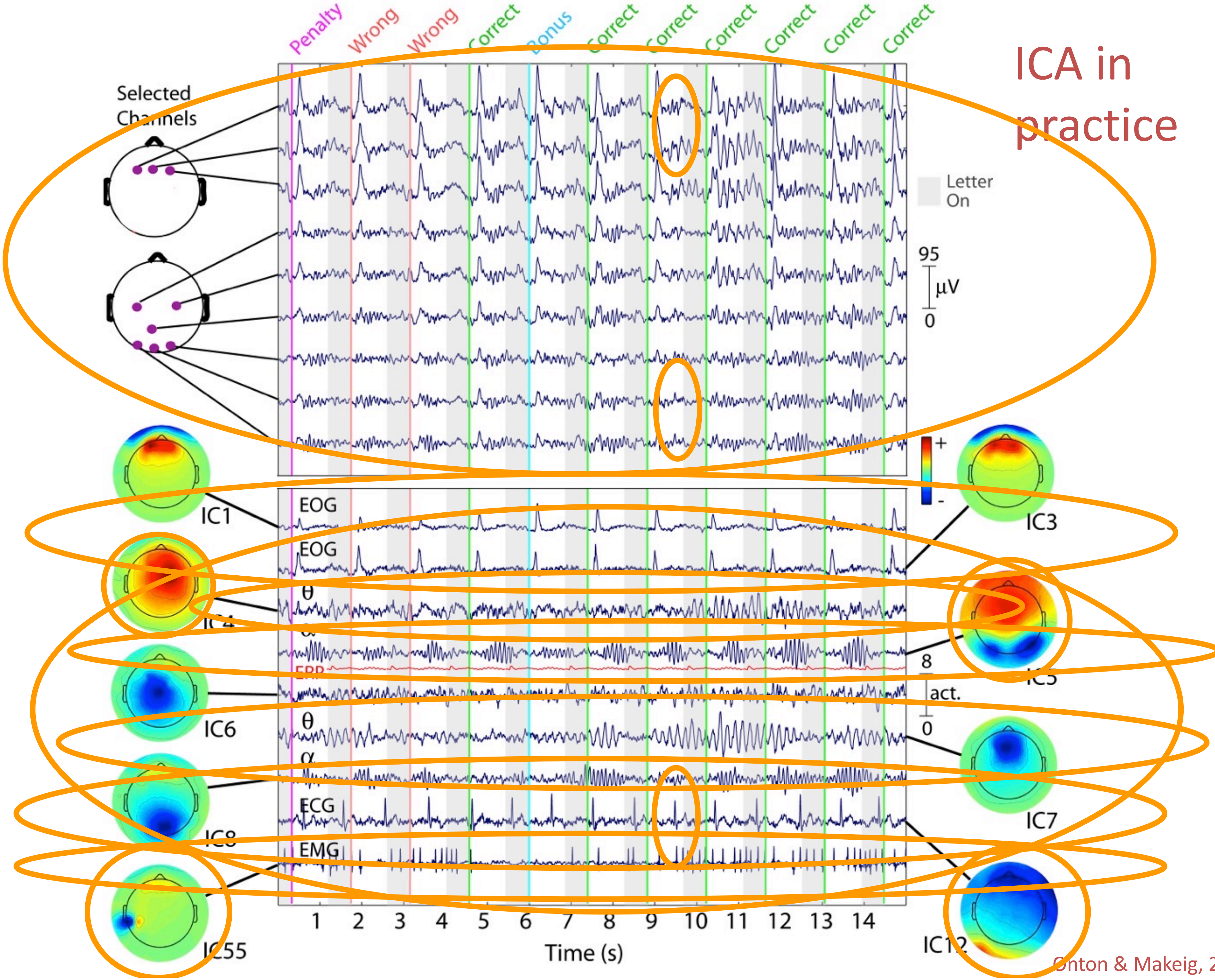
ICLabel: A crowd-sourced AI independent component classifier



labeling.ucsd.edu/tutorial

Luca Pion-Tonachini, 2019

ICA in practice



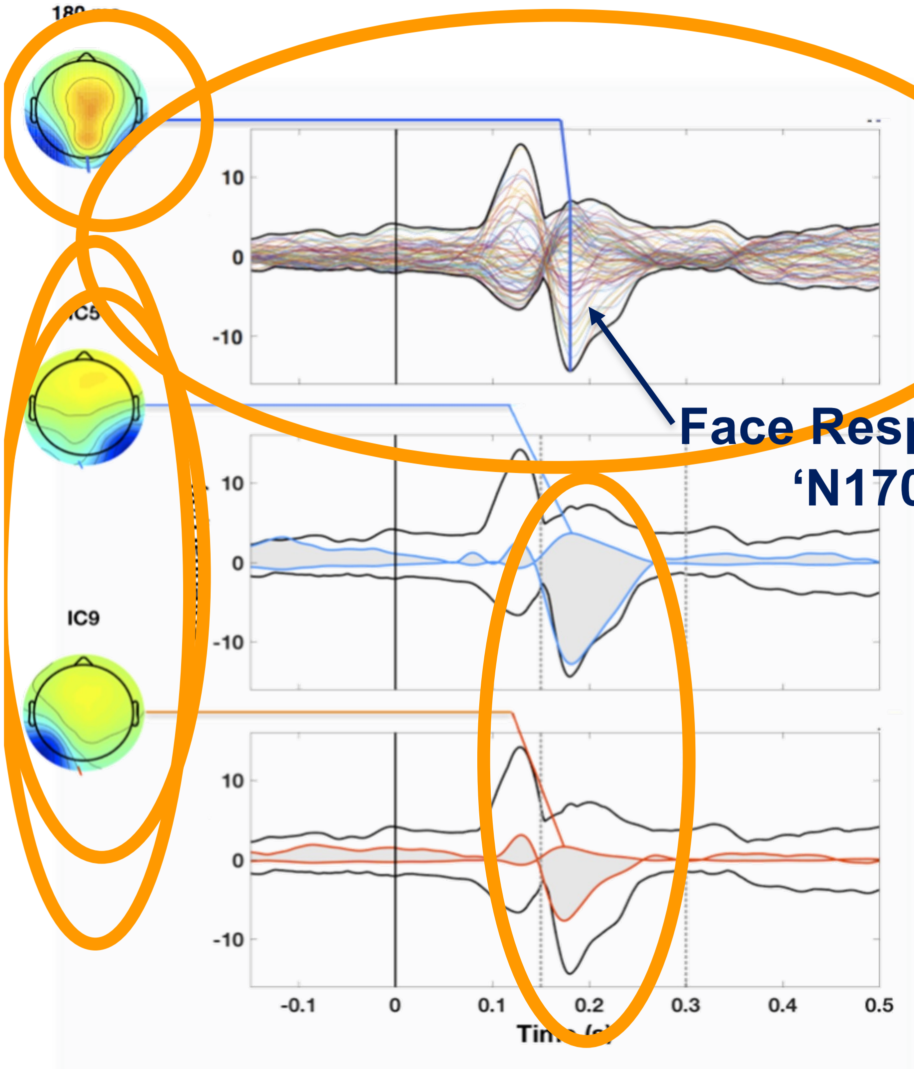
Onton & Makeig, 2006

EEG & *knowing*

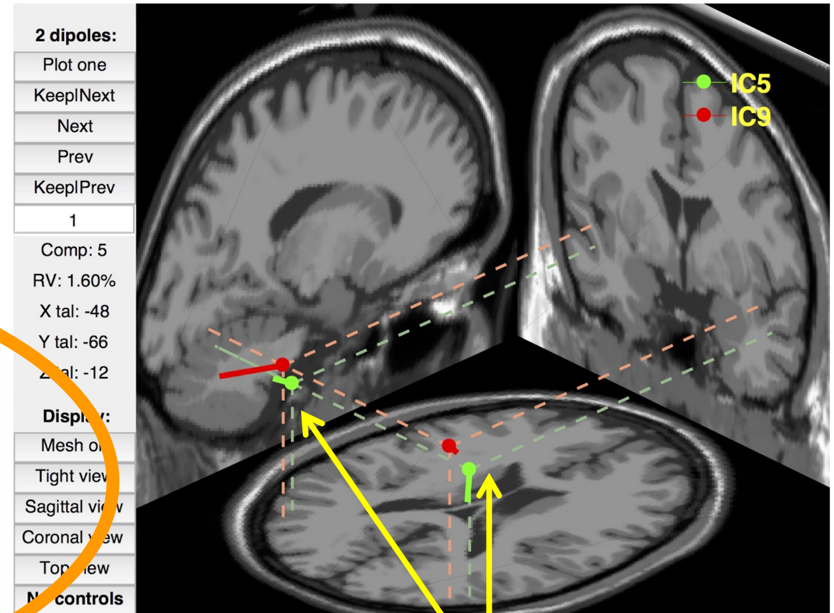
Knowing

Face Perception

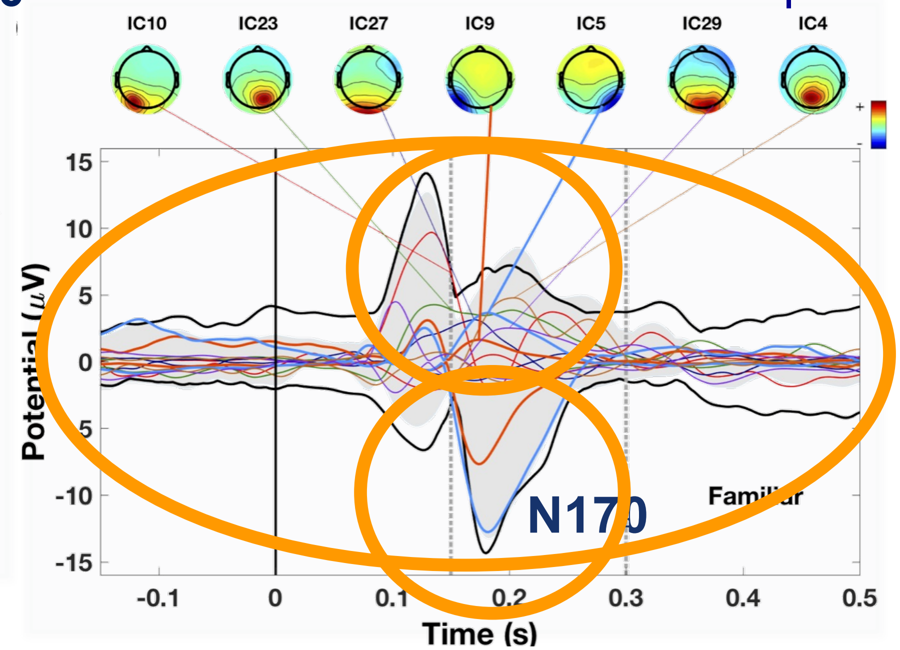
Subject indicates, “I see a face photo.”
versus, “I see a house photo.”



Face Response
‘N170’



Face area in bilateral
inferior temporal cortex



S Makeig, 2017

Schizophrenia

Auditory Passive Oddball Task (SZ, Cntrl)

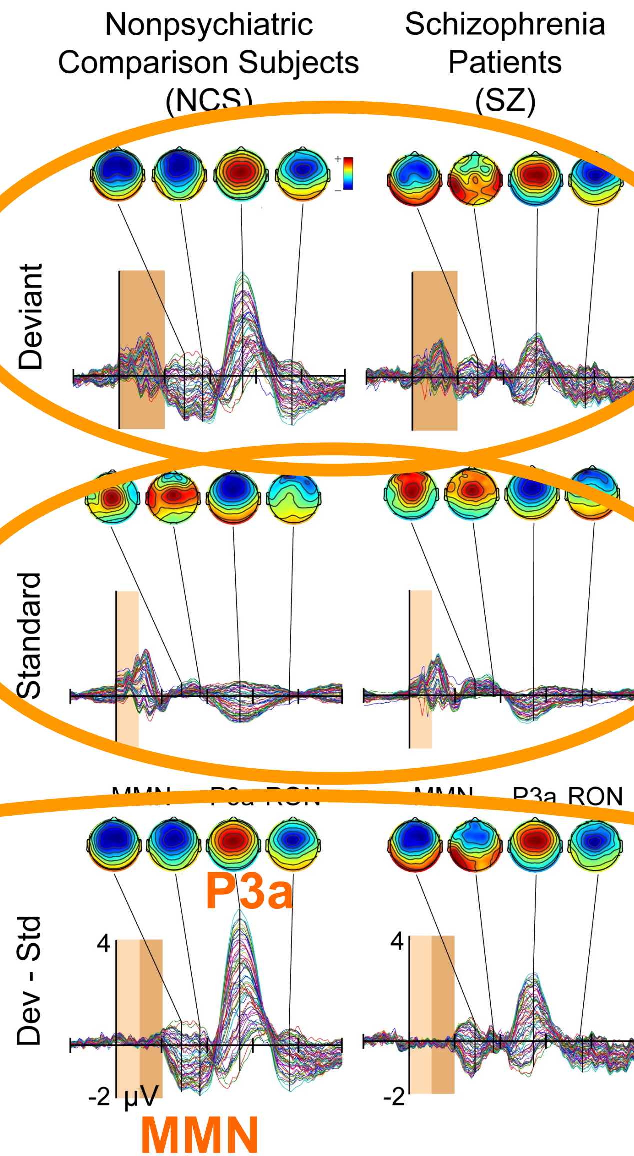
Duration Deviants

–

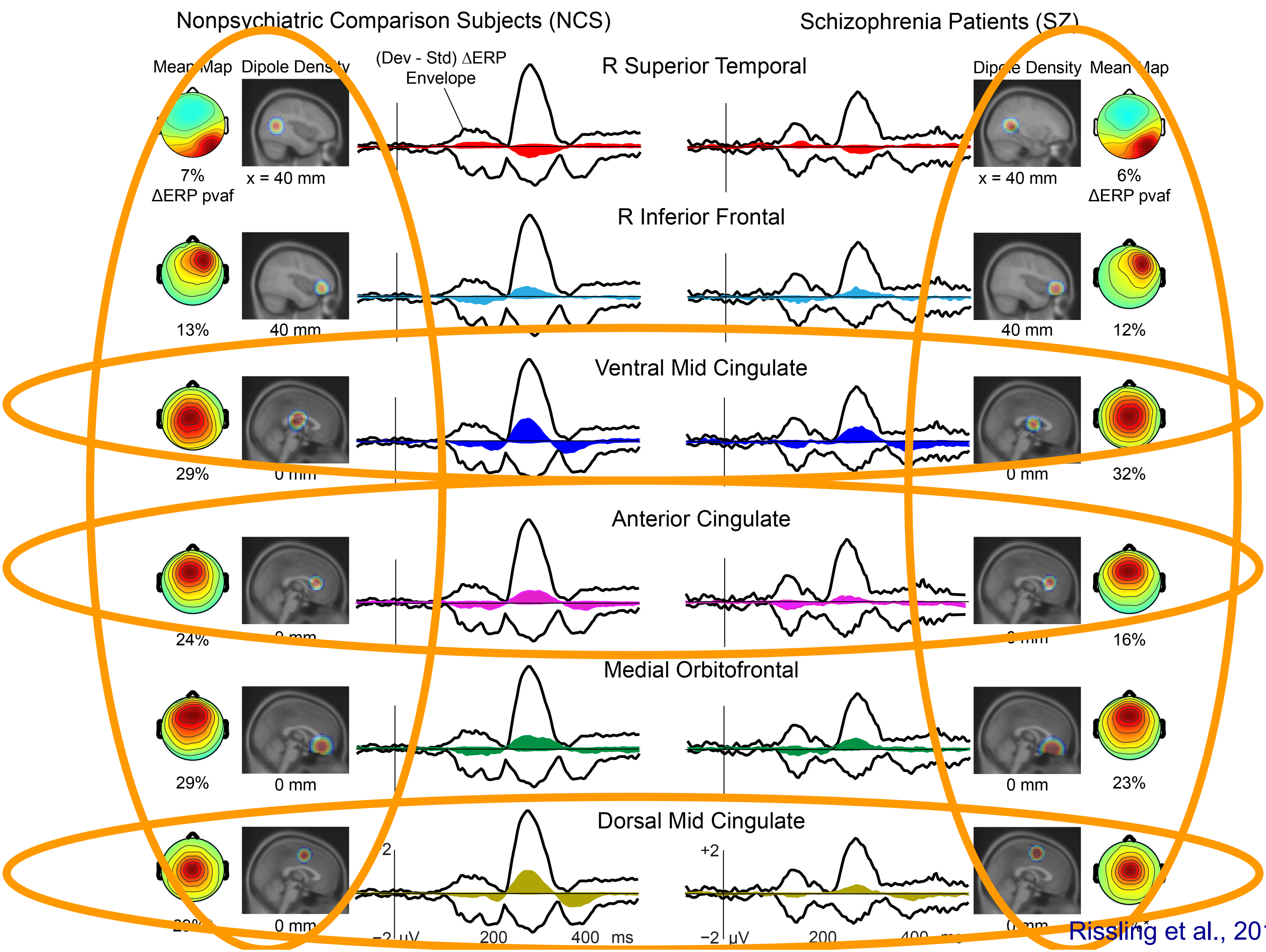
Standards

=

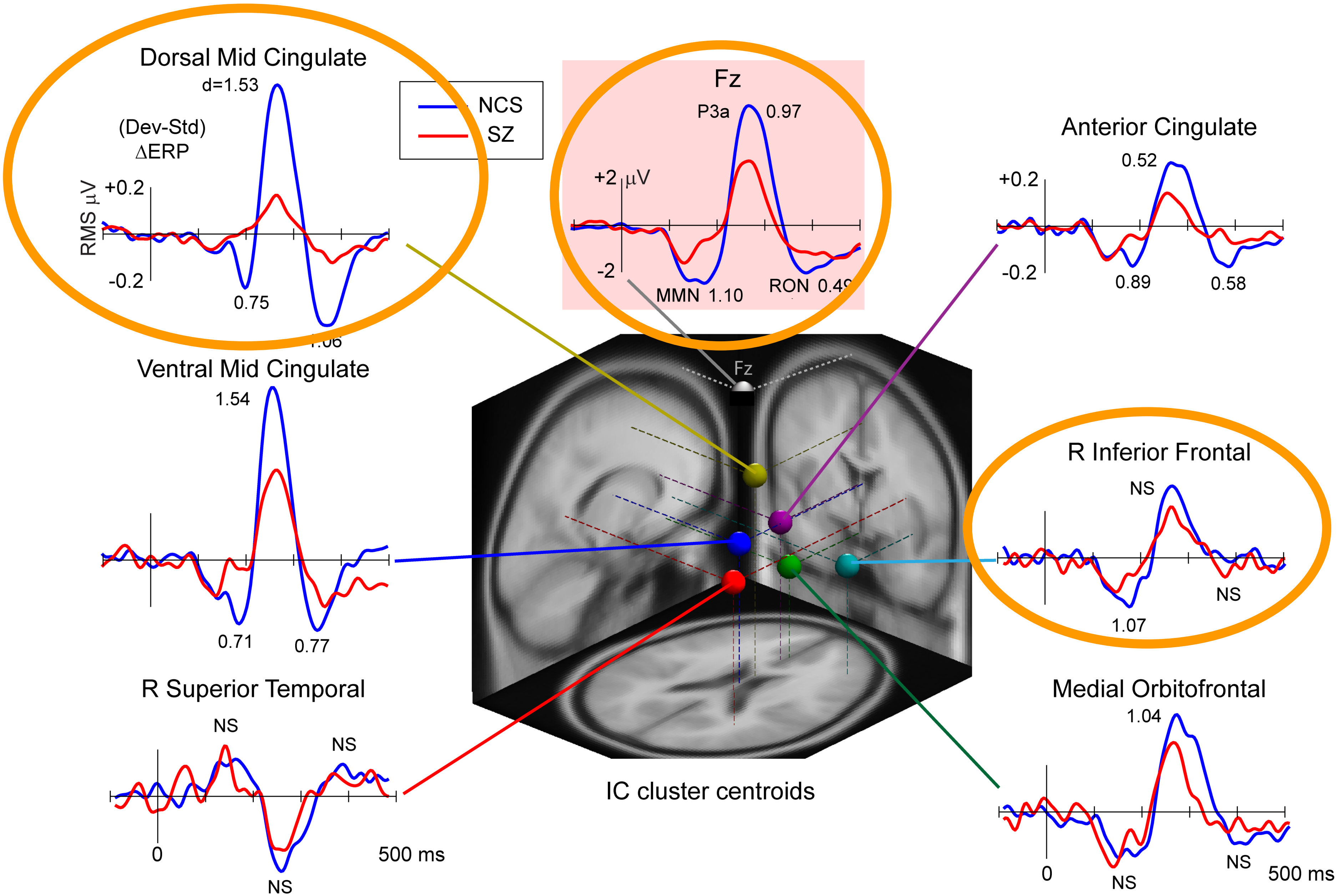
Auditory Deviance Response



Rissling et al., 2014



Rissling et al., 2014

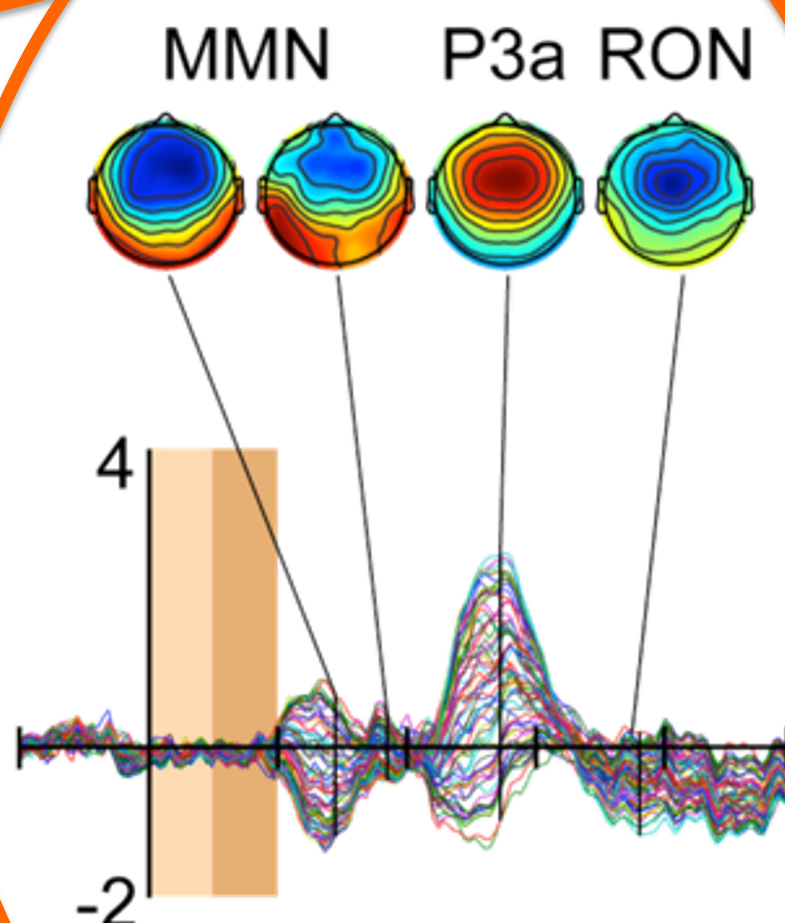


Rissling et al., 2014

PEAK AMPLITUDES	ERP	r^2
Scalp Electrode (Fz)		
Verbal IQ (WRAT)	P3a	[illegible]
Functional Capacity (UPSA)	RON	[illegible]
R Superior Temporal		
Working Memory (LNS Reorder)	RON	0.15
Verbal IQ (WRAT)	RON	0.15
Immediate Verbal Memory (CVLT)	**RON**	**0.28**
Delayed Verbal Memory (CVLT)	RON	0.26
Functional Capacity (UPSA)	**MMN**	**0.48**
Functional Capacity (UPSA)	RON	0.26
R Inferior Frontal		
Negative Symptoms (SANS)	**RON**	**0.36**
Psychosocial Functioning (SOF)	RON	0.24
Auditory Attention (LNS Forward)	**MMN**	**0.38**
Working Memory (LNS Reorder)	**MMN**	**0.30**
Verbal IQ (WRAT)	**MMN**	**0.46**
Ventral Mid Cingulate		
Positive Symptoms (SAPS)	**RON**	**0.29**
Negative Symptoms (SANS)	**P3a**	**0.36**
Immediate Verbal Memory (CVLT)	**RON**	**0.41**
Delayed Verbal Memory (CVLT)	RON	0.24
Verbal IQ (WRAT)	**RON**	**0.29**
Executive Functioning (WCST)	RON	0.24
Anterior Cingulate		
Functional Status (GAF)	MMN	0.18
Functional Status (GAF)	RON	0.17
Immediate Verbal Memory (CVLT)	RON	0.25
Delayed Verbal Memory (CVLT)	RON	0.17
Medial Oribitofrontal		
Positive Symptoms (SAPS)	**P3a**	**0.40**
Negative Symptoms (SANS)	**P3a**	**0.54**
Psychosocial Functioning (SOF)	**P3a**	**0.37**
Functional Capacity (UPSA)	**P3a**	**0.32**
Dorsal Mid Cingulate		
Verbal IQ (WRAT)	P3a	0.15
Executive Functioning (WCST)	MMN	0.18

X

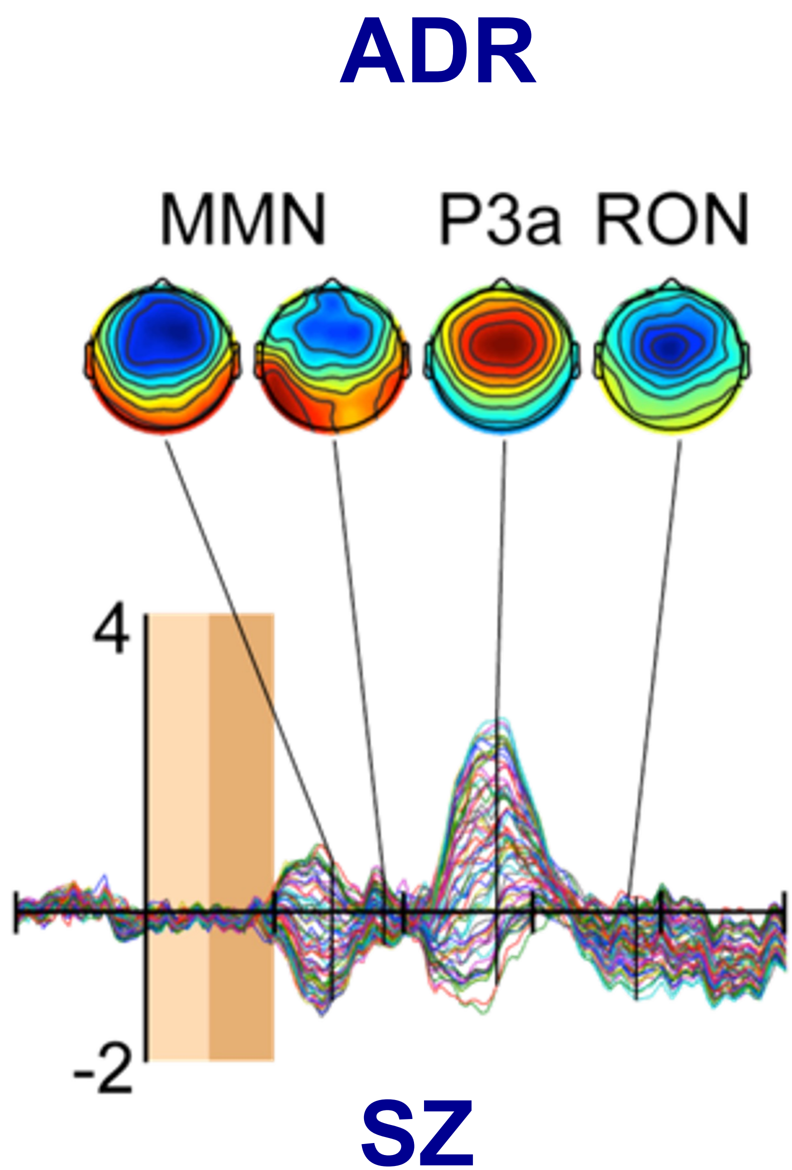
ADR



SZ

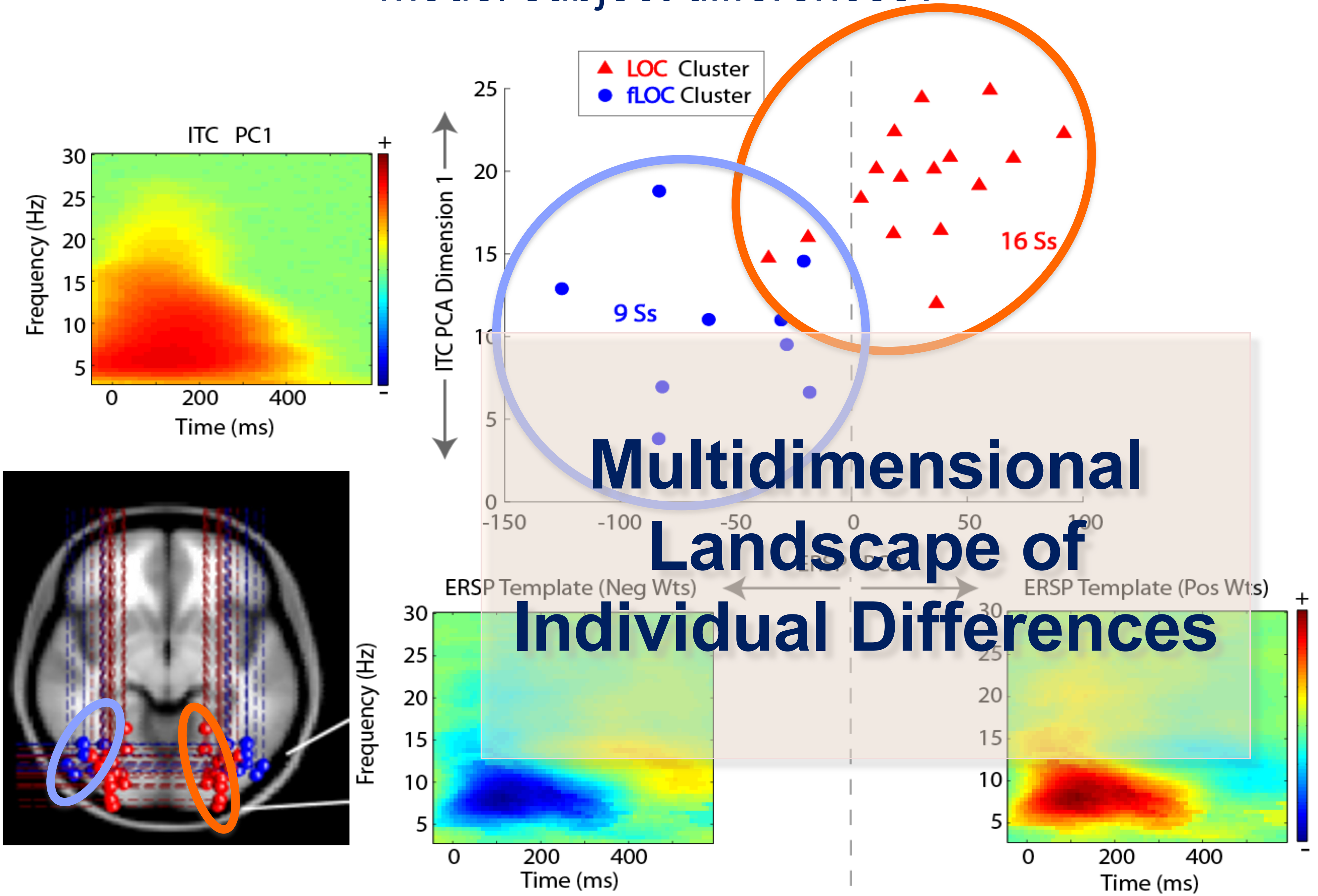
Rissling et al., 2014

PEAK LATENCIES	ERP	r^2
Scalp Electrode (Fz)		
---n/a---	---	X
R Superior Temporal		
Functional capacity (UPSA)	MMN	0.25
Delayed Verbal Memory (CVLT)	MMN	0.17
R Inferior Frontal		
Negative Symptoms (SANS)	**RON**	**0.51**
Psychosocial Functioning (SOF)	RON	0.25
Executive Functioning (WCST)	**MMN**	**0.30**
Executive Functioning (WCST)	**P3a**	**0.28**
Ventral Mid Cingulate		
Negative Symptoms (SANS)	**P3a**	**0.33**
Negative Symptoms (SANS)	**RON**	**0.33**
Psychosocial Functioning (SOF)	**P3a**	**0.31**
Verbal IQ (WRAT)	MMN	0.25
Executive Functioning (WCST)	**P3a**	**0.30**
Anterior Cingulate		
Functional Capacity (UPSA)	RON	0.17
Verbal IQ (WRAT)	MMN	0.24
Auditory Attention (LNS-Forward)	MMN	0.17
Medial Orbitofrontal		
Negative Symptoms (SANS)	**RON**	**0.41**
Positive Symptoms (SAPS)	**RON**	**0.40**
Auditory Attention (LNS-Forward)	**MMN**	**0.29**
Executive Functioning (WCST)	**P3a**	**0.32**
Dorsal Mid Cingulate		
Negative Symptoms (SANS)	MMN	0.20
Negative Symptoms (SANS)	P3a	0.17
Global Functioning (GAF)	RON	0.24
Functional Capacity (UPSA)	P3a	0.13



Rissling et al., 2014

Can measures of source-resolved EEG dynamics model subject differences?



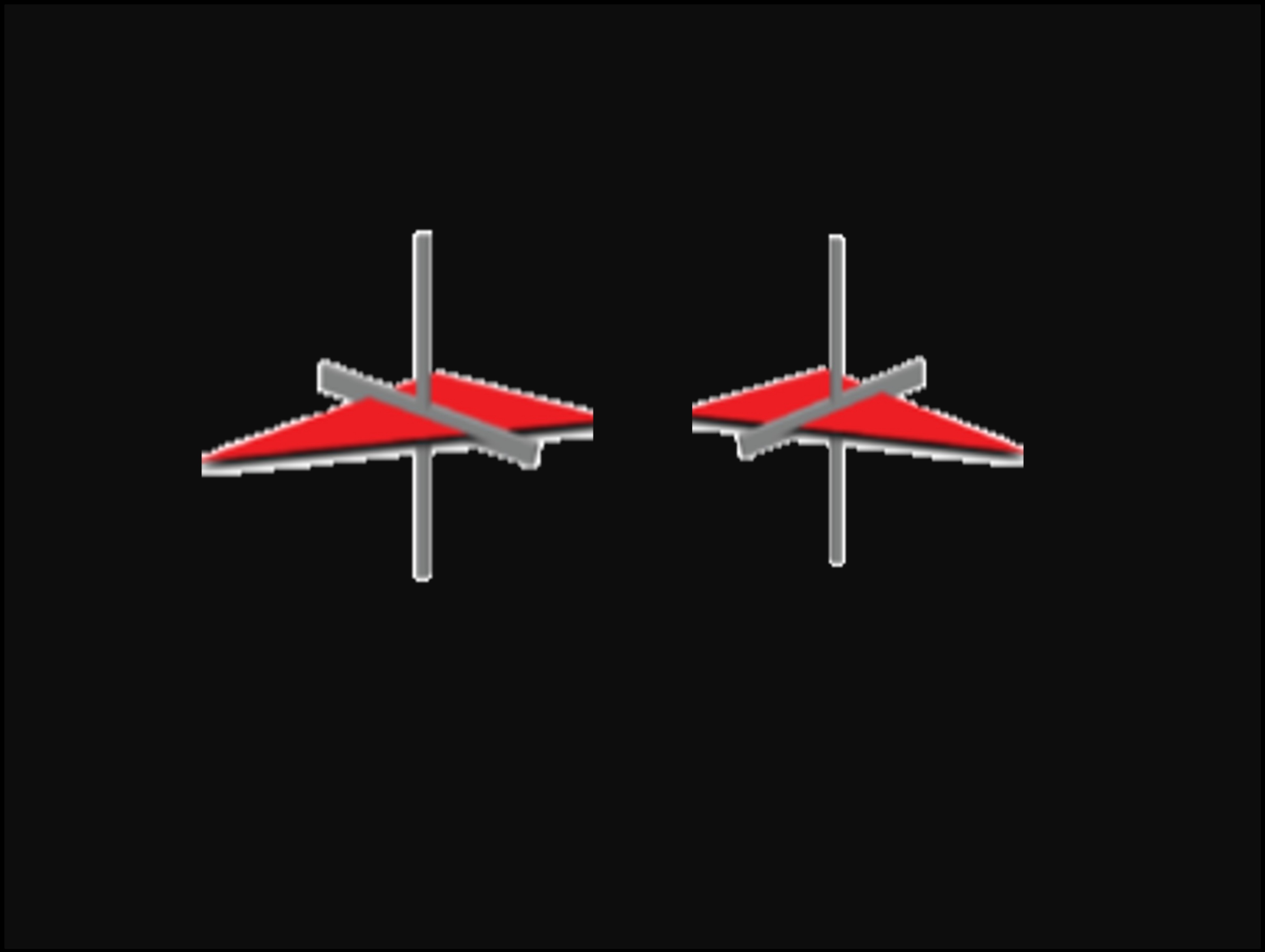

Klaus Gramann
3-D Tunnel Task

A Passive Spatial Navigation Paradigm

Klaus Gramann et al., 2010

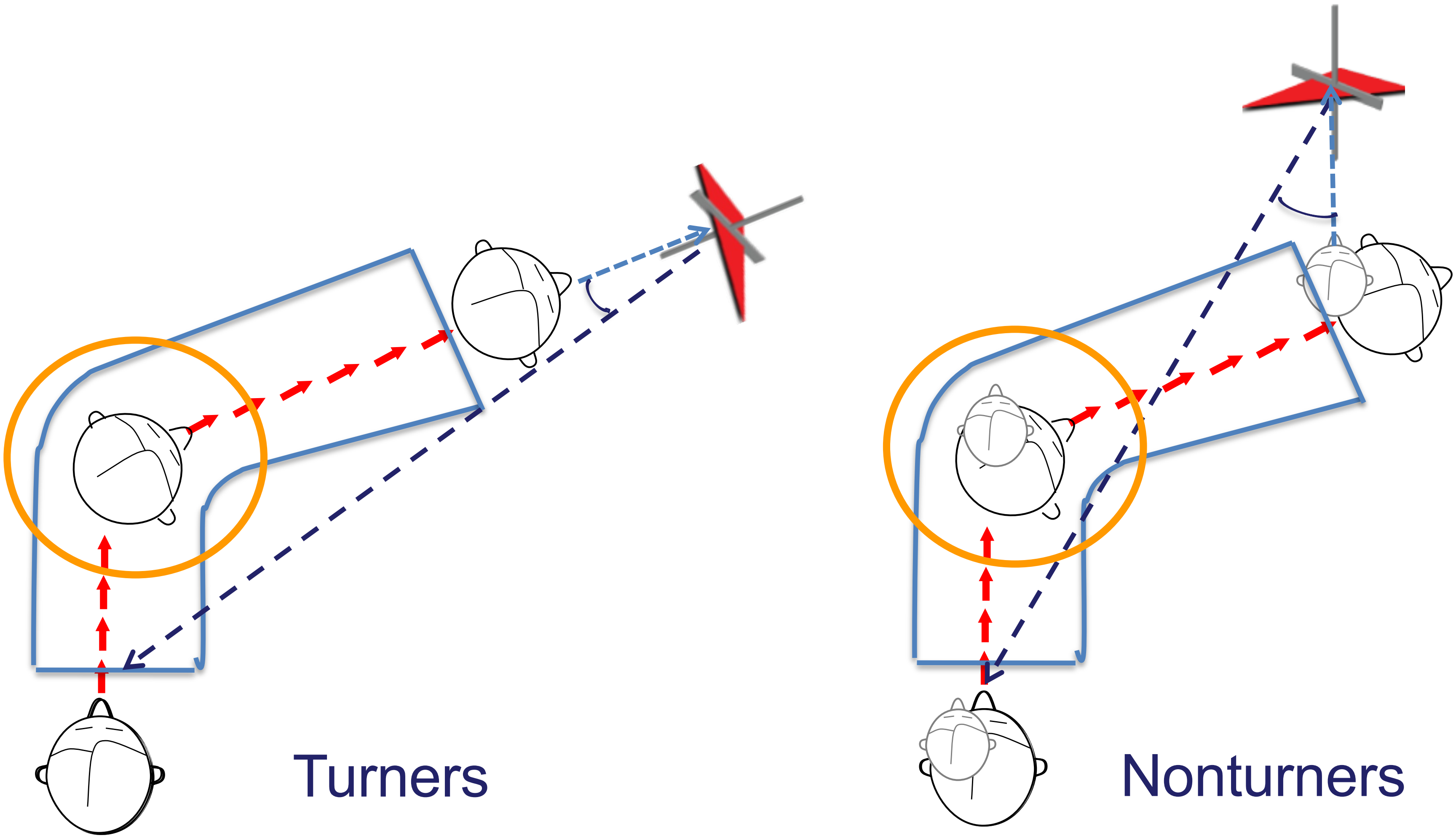
Klaus Gramann et al., 2010

A Passive Spatial Navigation Paradigm



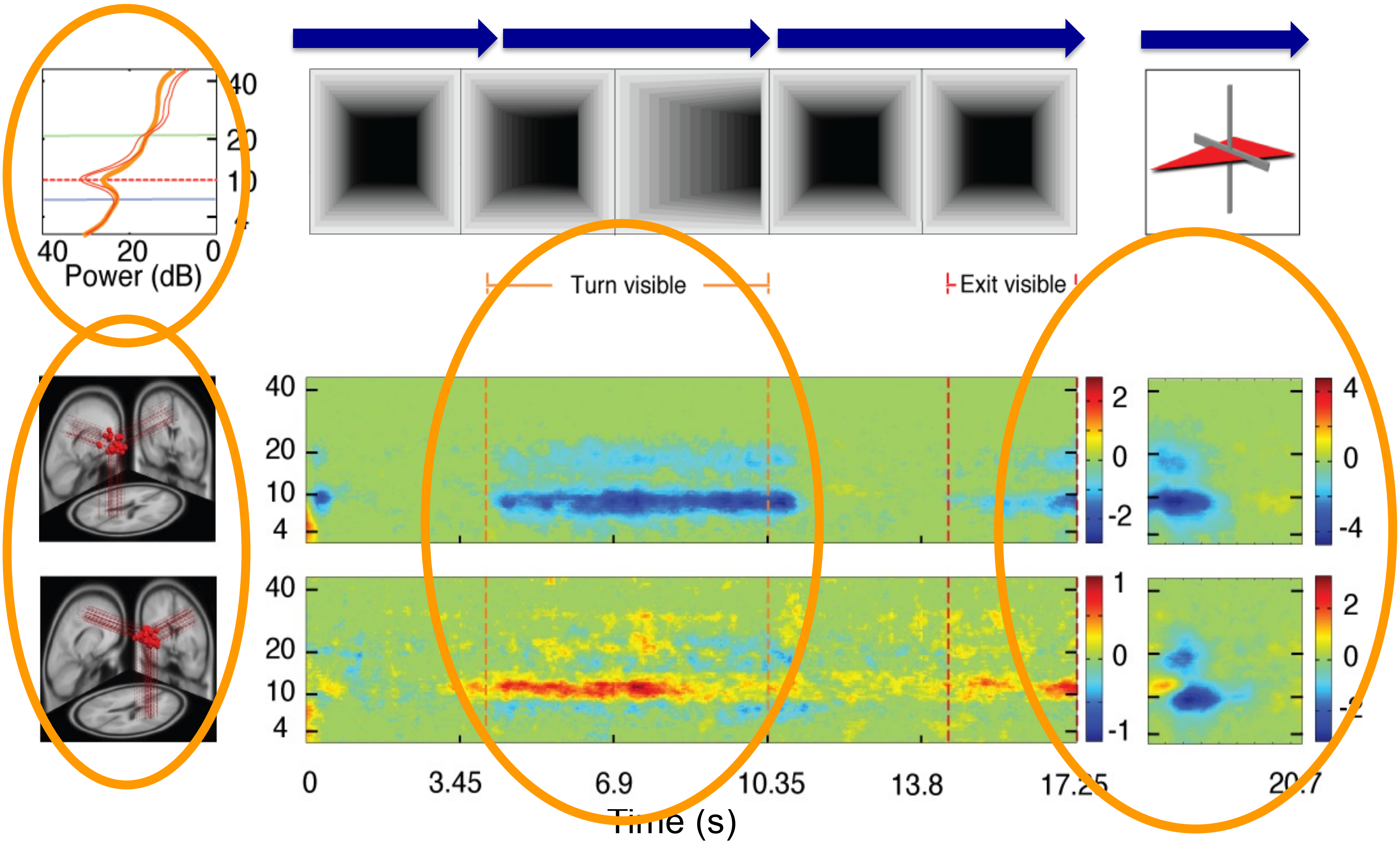
Klaus Gramann et al., 2010

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



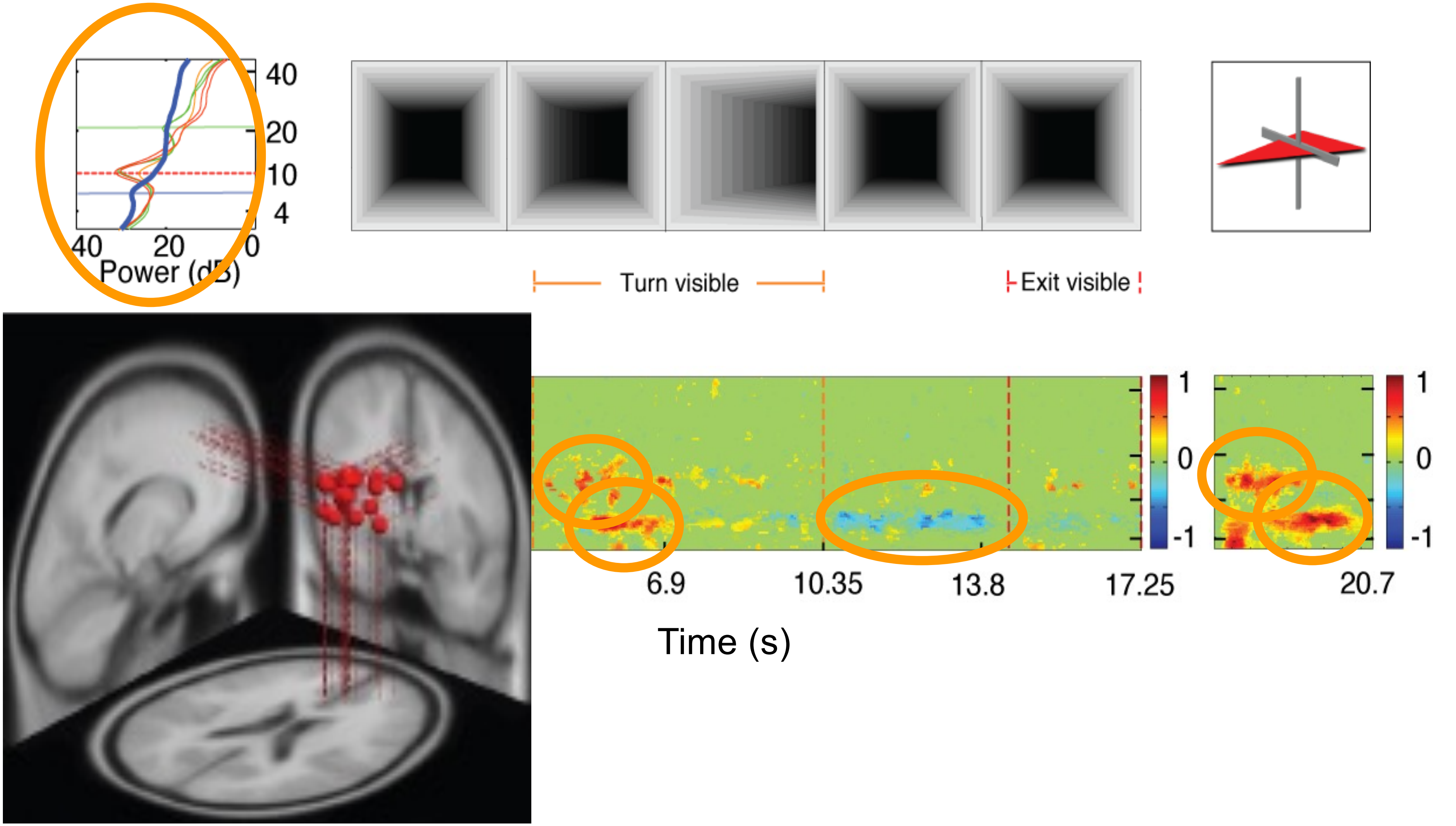
Klaus Gramann & S. Makeig, 2010

Two parietal component clusters



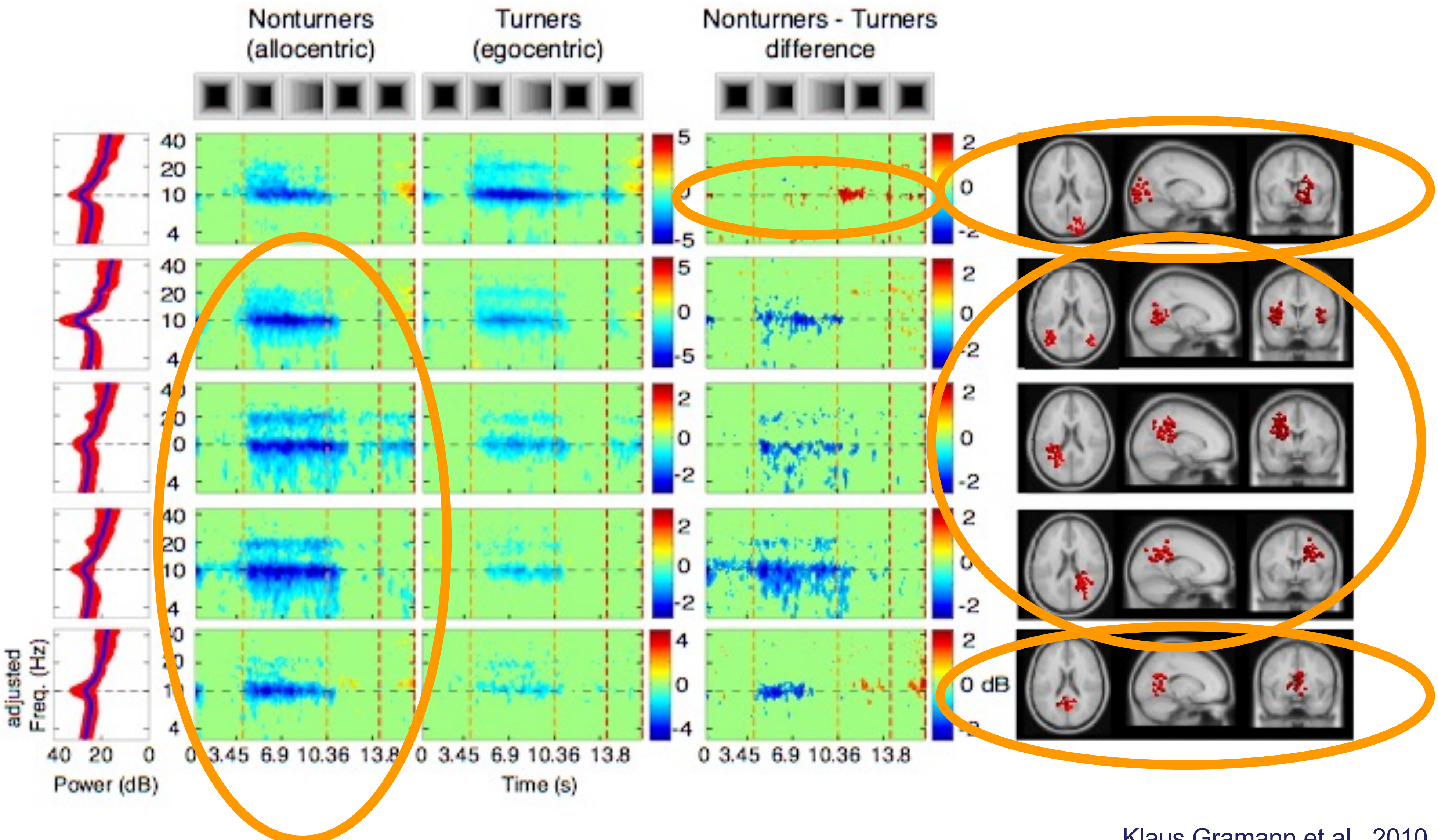
Klaus Gramann et al., 2010

Medial prefrontal component cluster



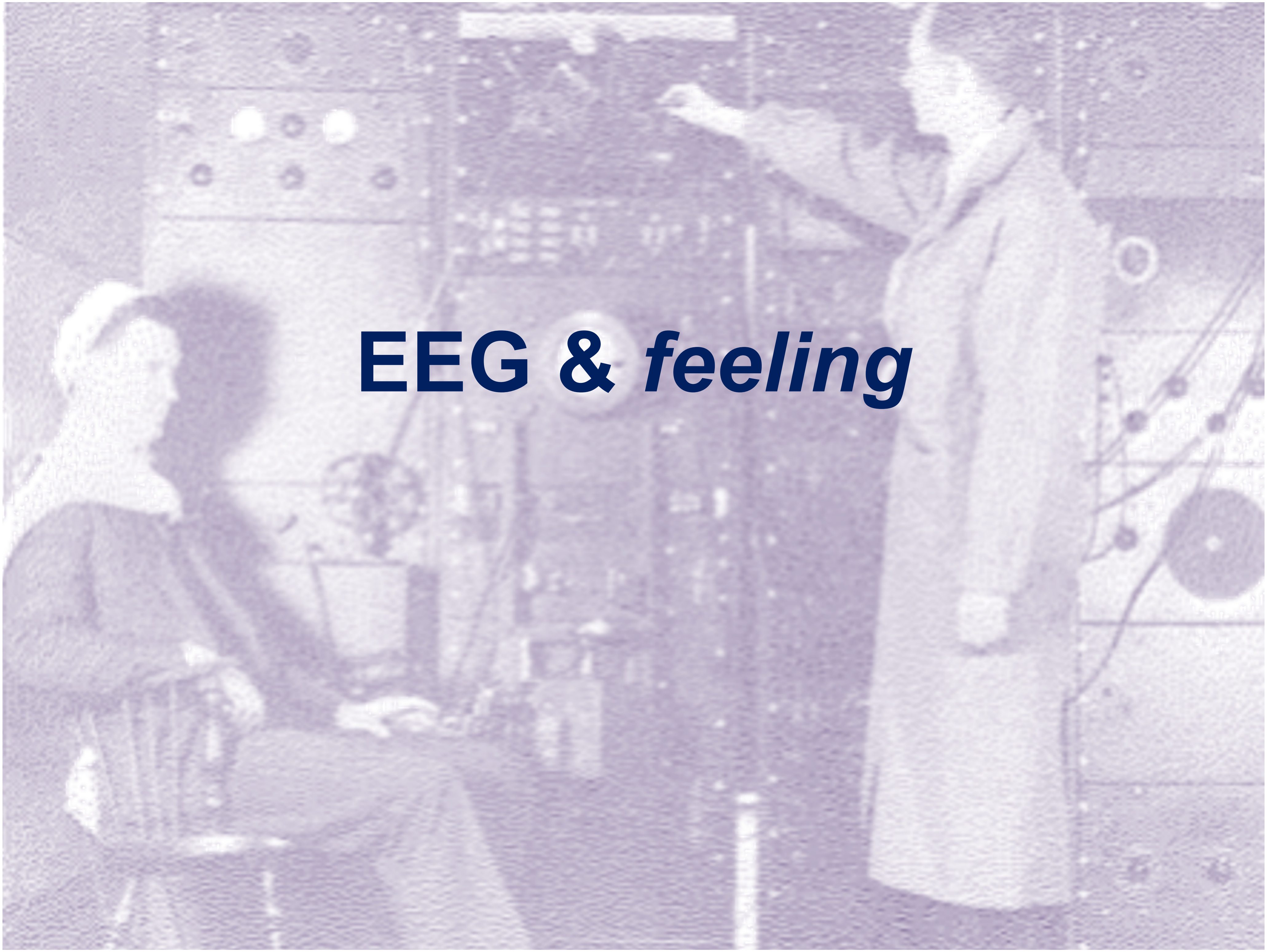
Klaus Gramann et al., 2010

Clusters distinguishing Turners & Nonturners

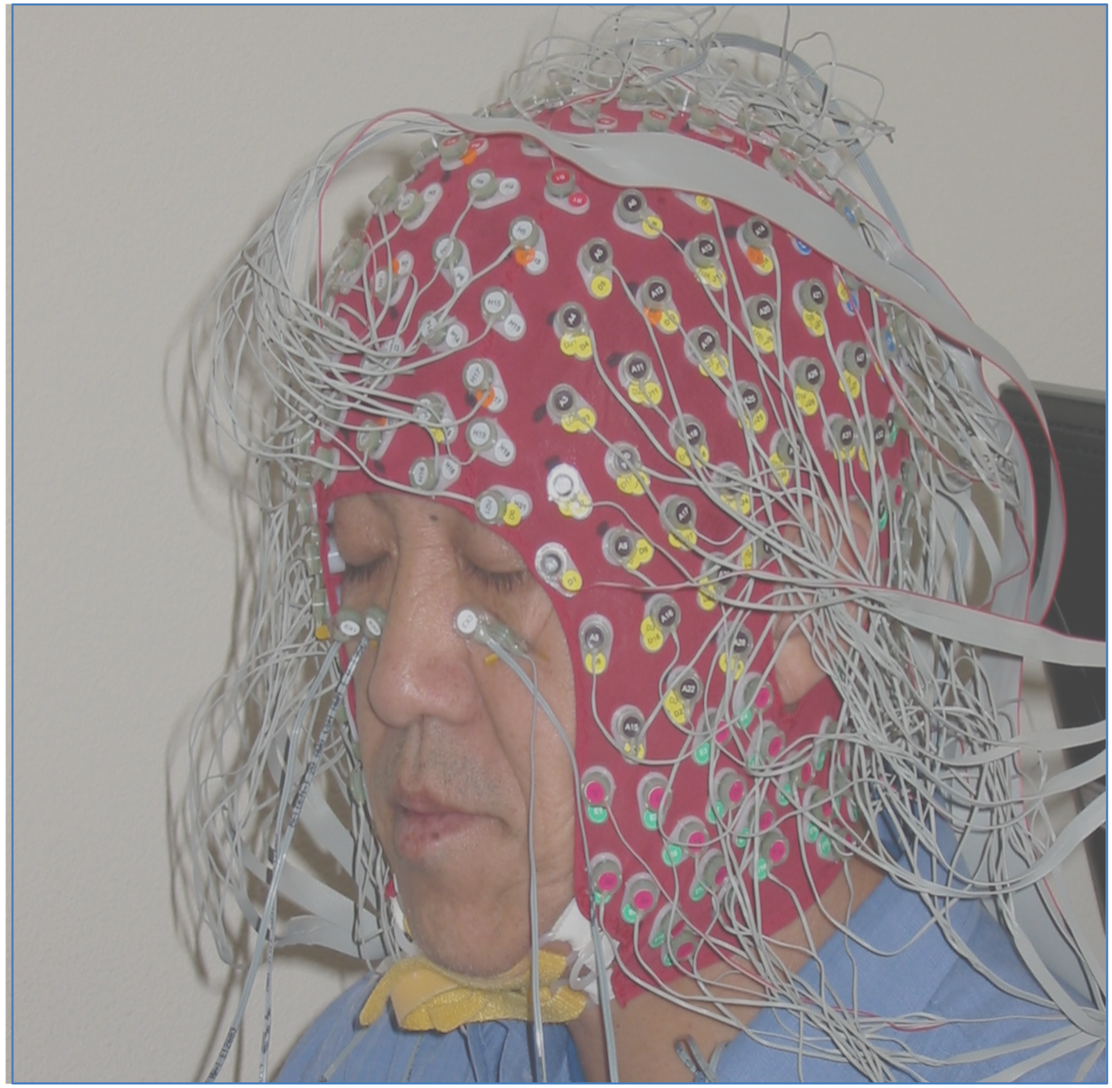


Klaus Gramann et al., 2010

EEG & *feeling*



EEG Dynamics of Emotion Imagination

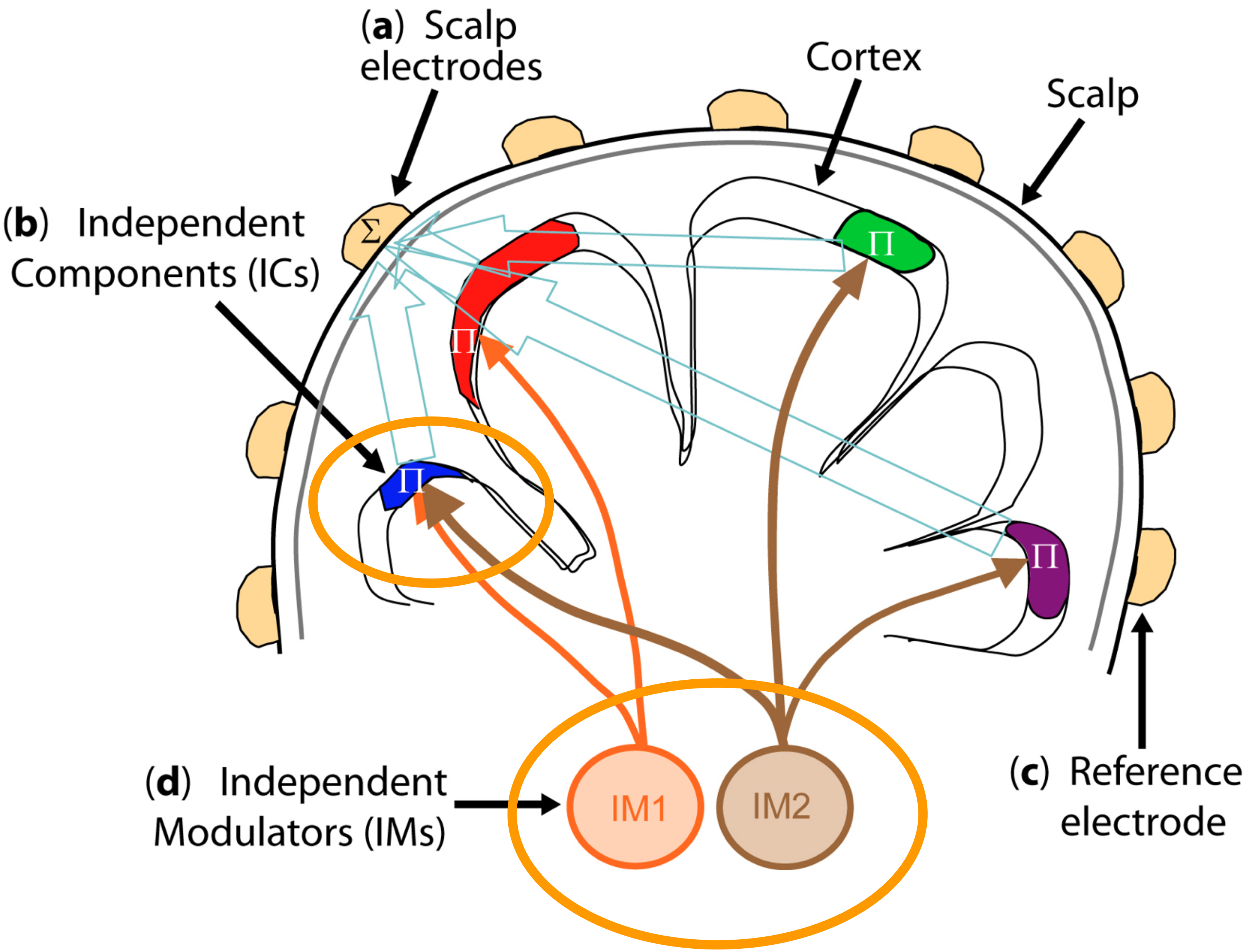


Suggest the imaginative experience of 15 emotions:

- after Helen Bonny
- initial relaxation instruction
- alternate suggestions to imagine scenes engendering positive and negative emotions
- relaxation instructions between emotion episodes
- **obtained 1-5 min periods of eyes-closed spontaneous EEG** for each emotion from 33 subjects.

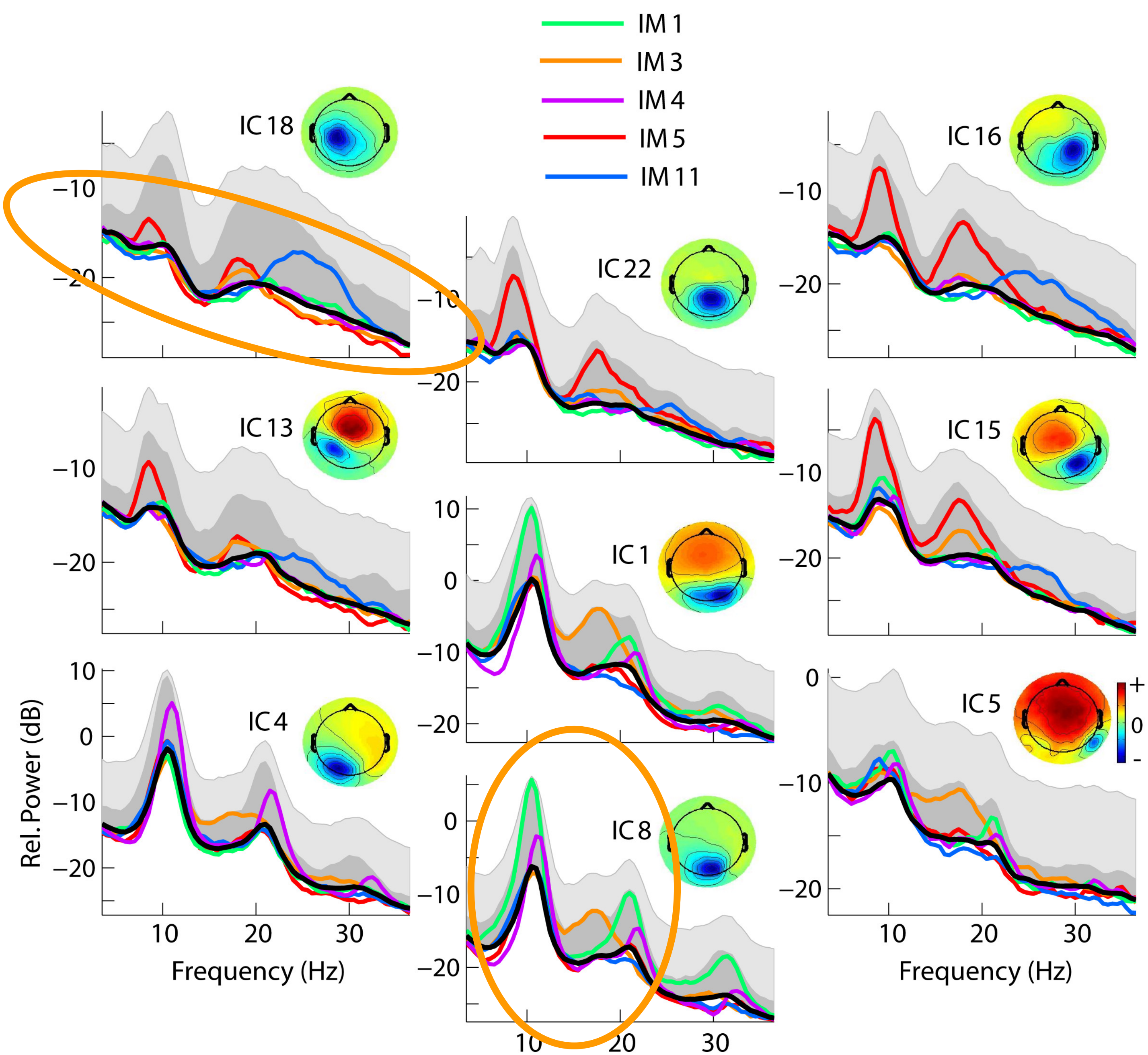
Onton & Makeig, *Frontiers in Human Neuroscience* ‘09

Independent Modulators

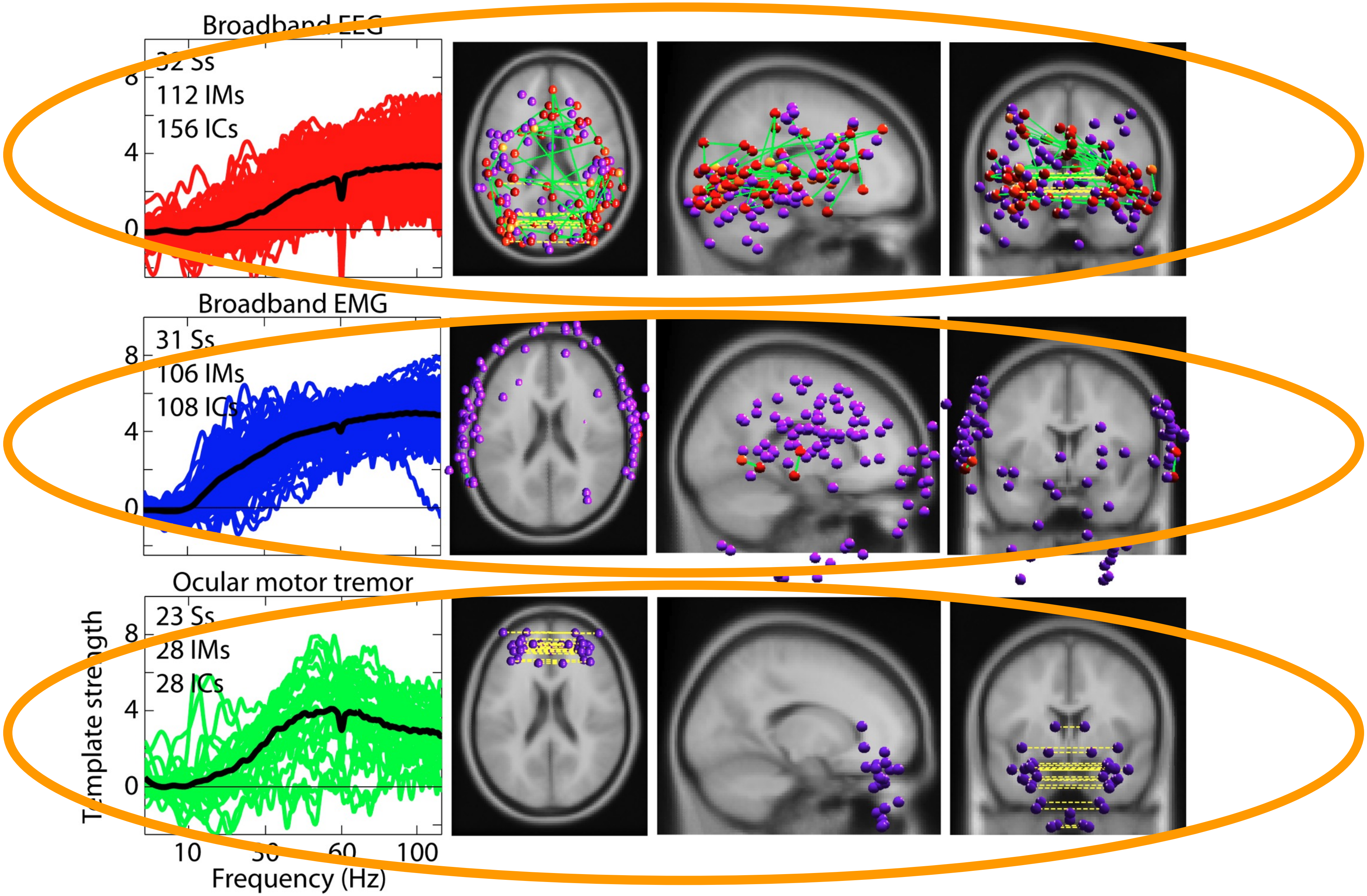


Onton & Makeig, *Frontiers in Human Neuroscience* '09

Independent Modulators

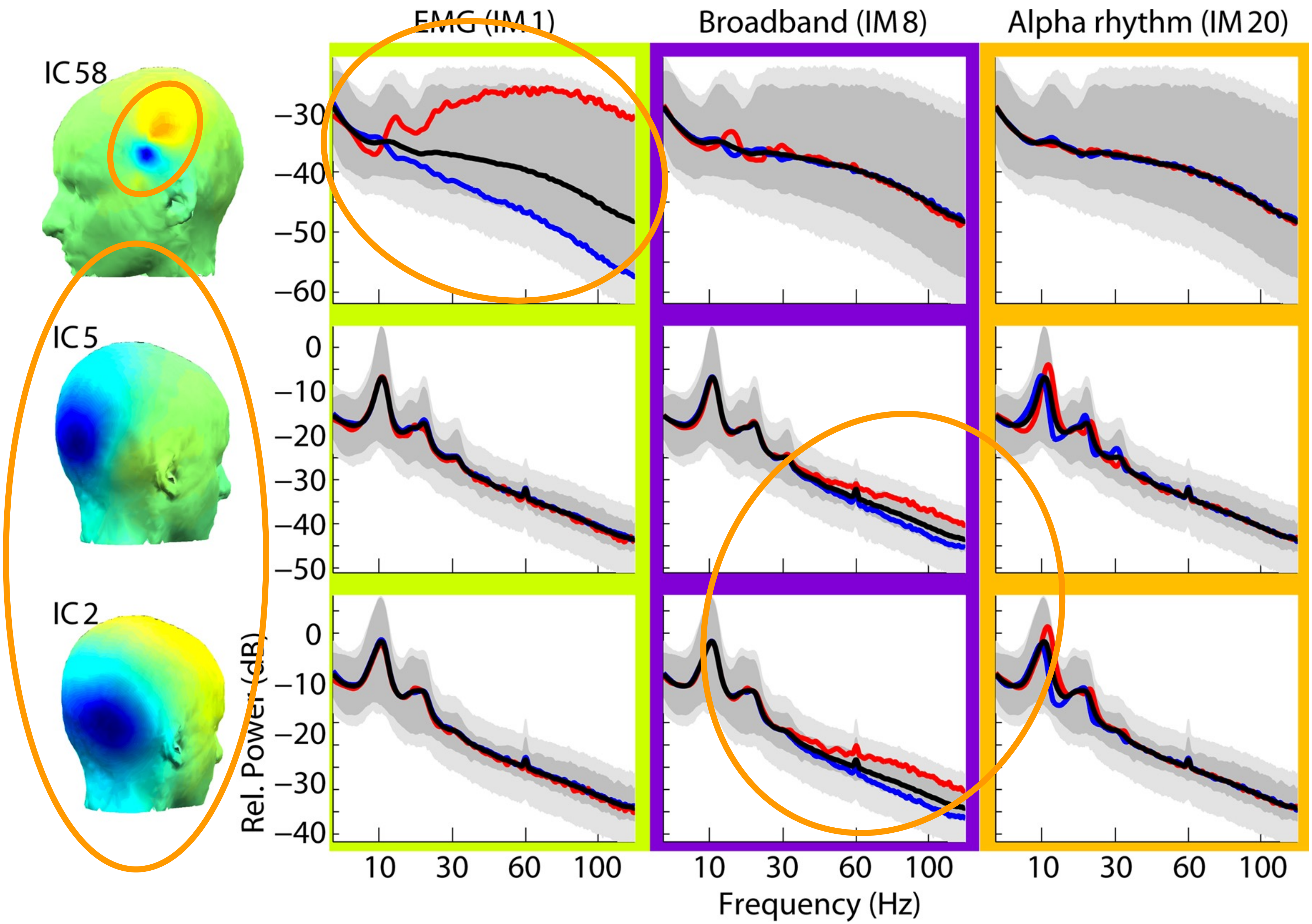


Onton & Makeig, *Frontiers in Human Neuroscience* '09



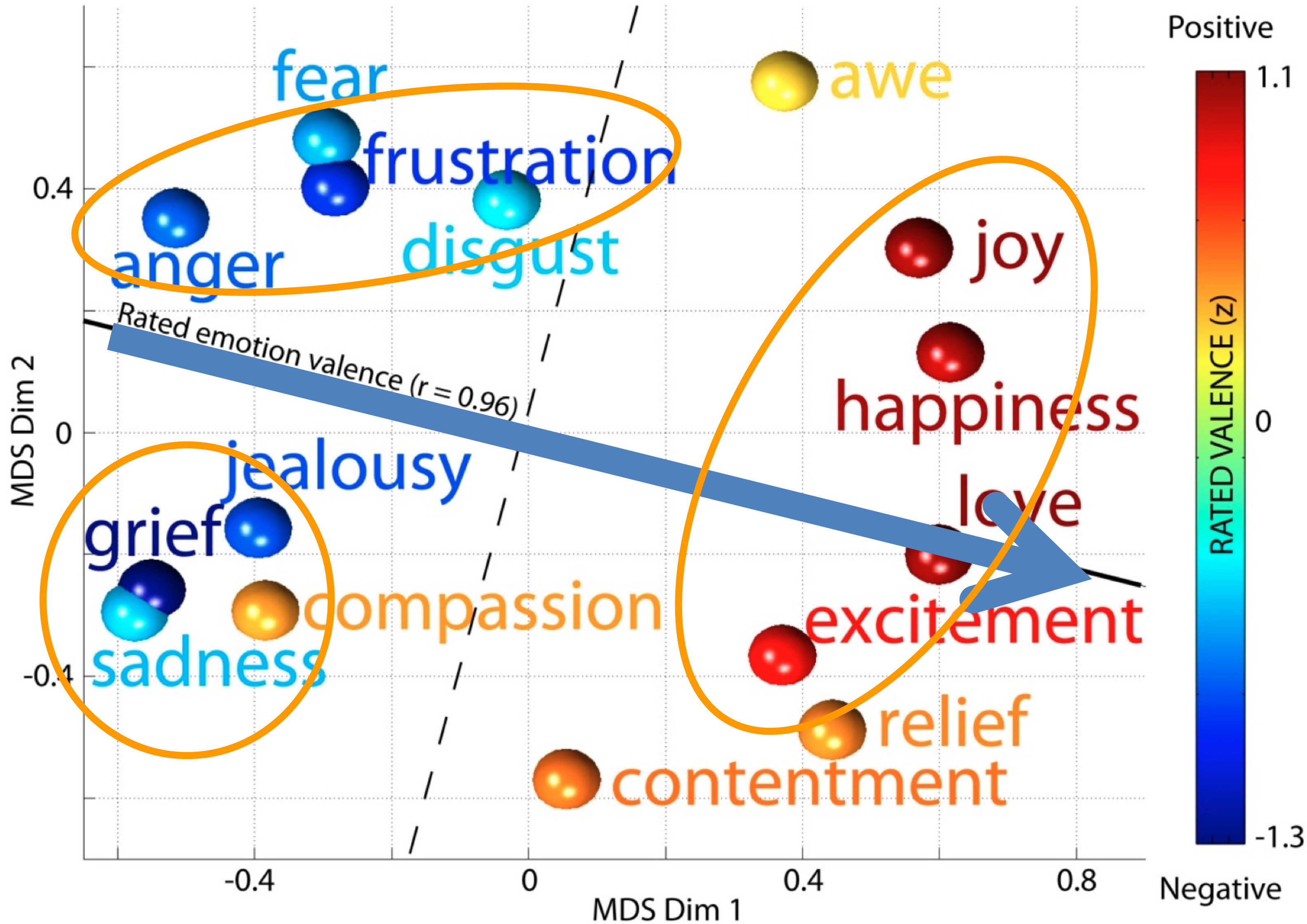
Onton & Makeig, *Frontiers in Human Neuroscience* '09

Independent Modulators

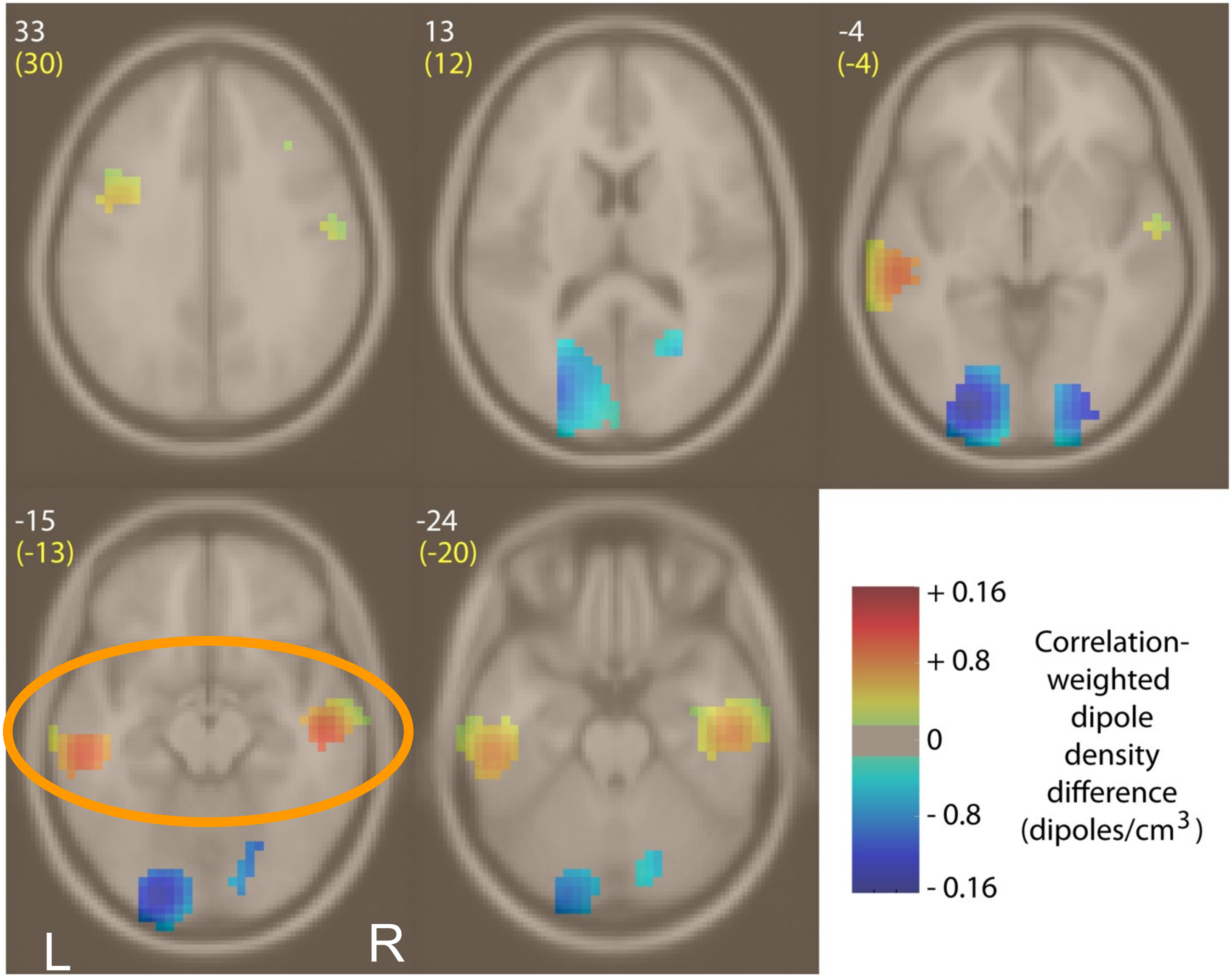


Onton & Makeig, *Frontiers in Human Neuroscience* '09

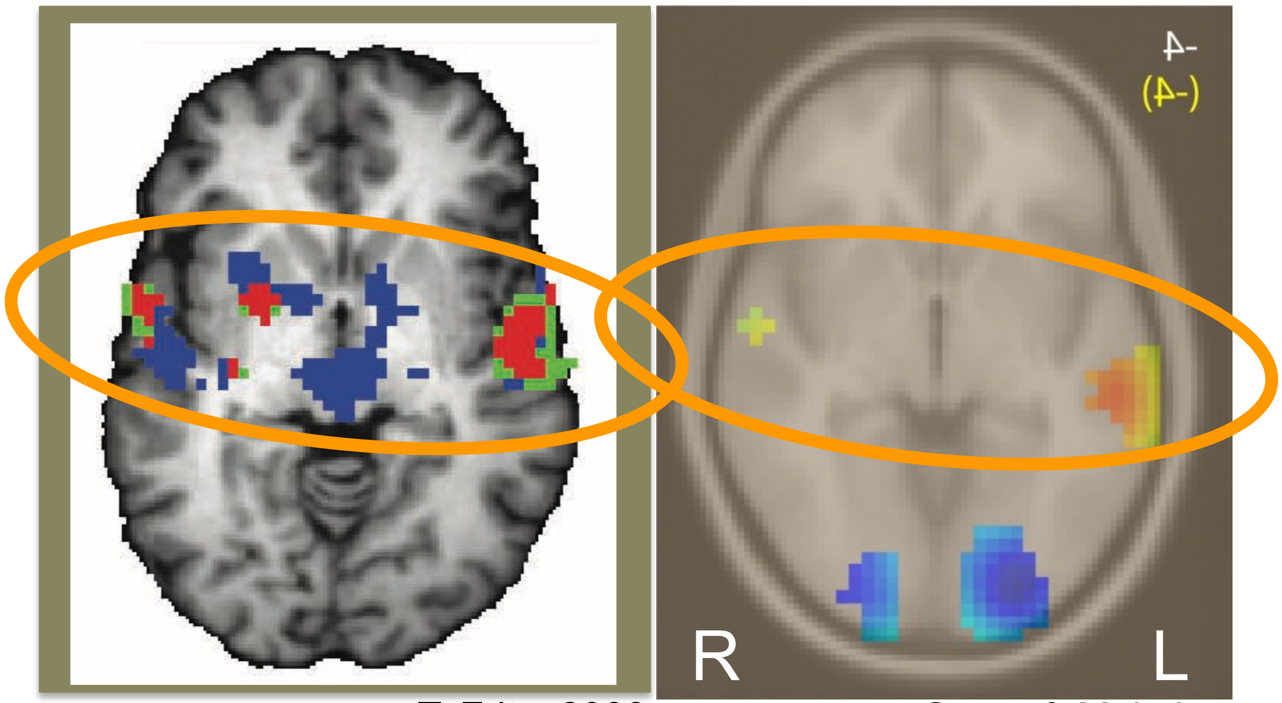
Changes in distribution of *broadband high-frequency* EEG power with imagined emotion



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



Onton & Makeig, *Frontiers in Human Neuroscience* '09

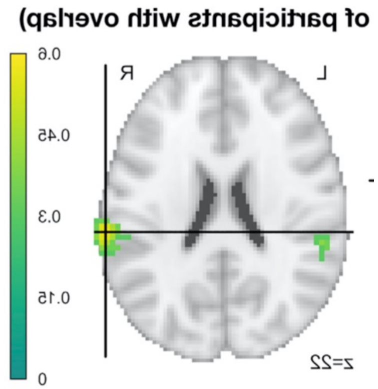


T. Fritz, 2009

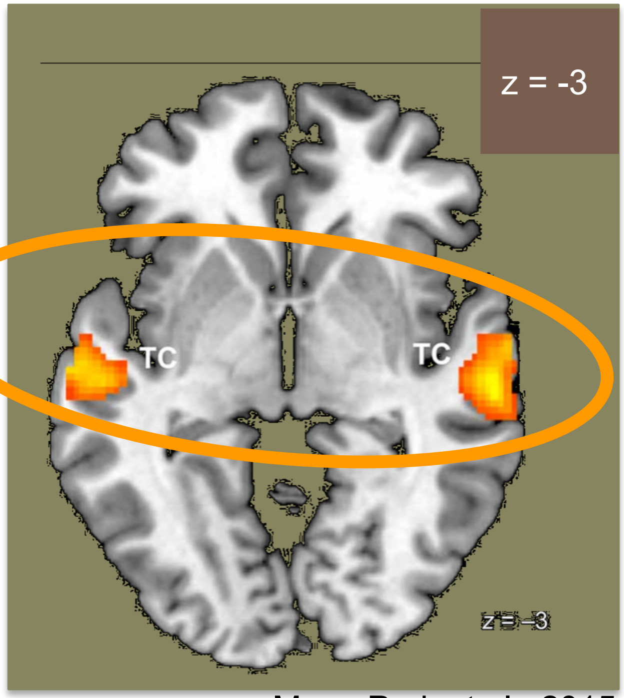
Onton & Makeig, 2009

fMRI BOLD

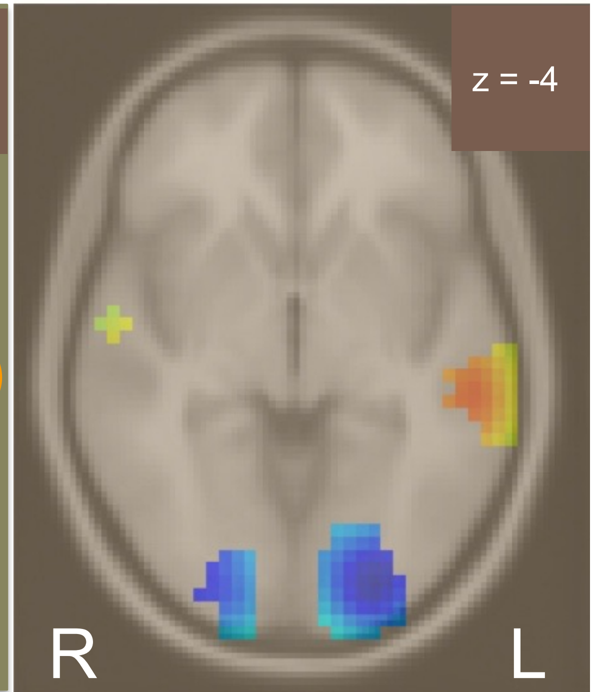
EEG



Sievers et al., 2021



Mona Park et al., 2015



Onton & Makeig 2009

fMRI BOLD

EEG
HFB

Swartz
Center for
Computational
Neuroscience

The Beginning

fEMI,

BMI,

MoBI ...