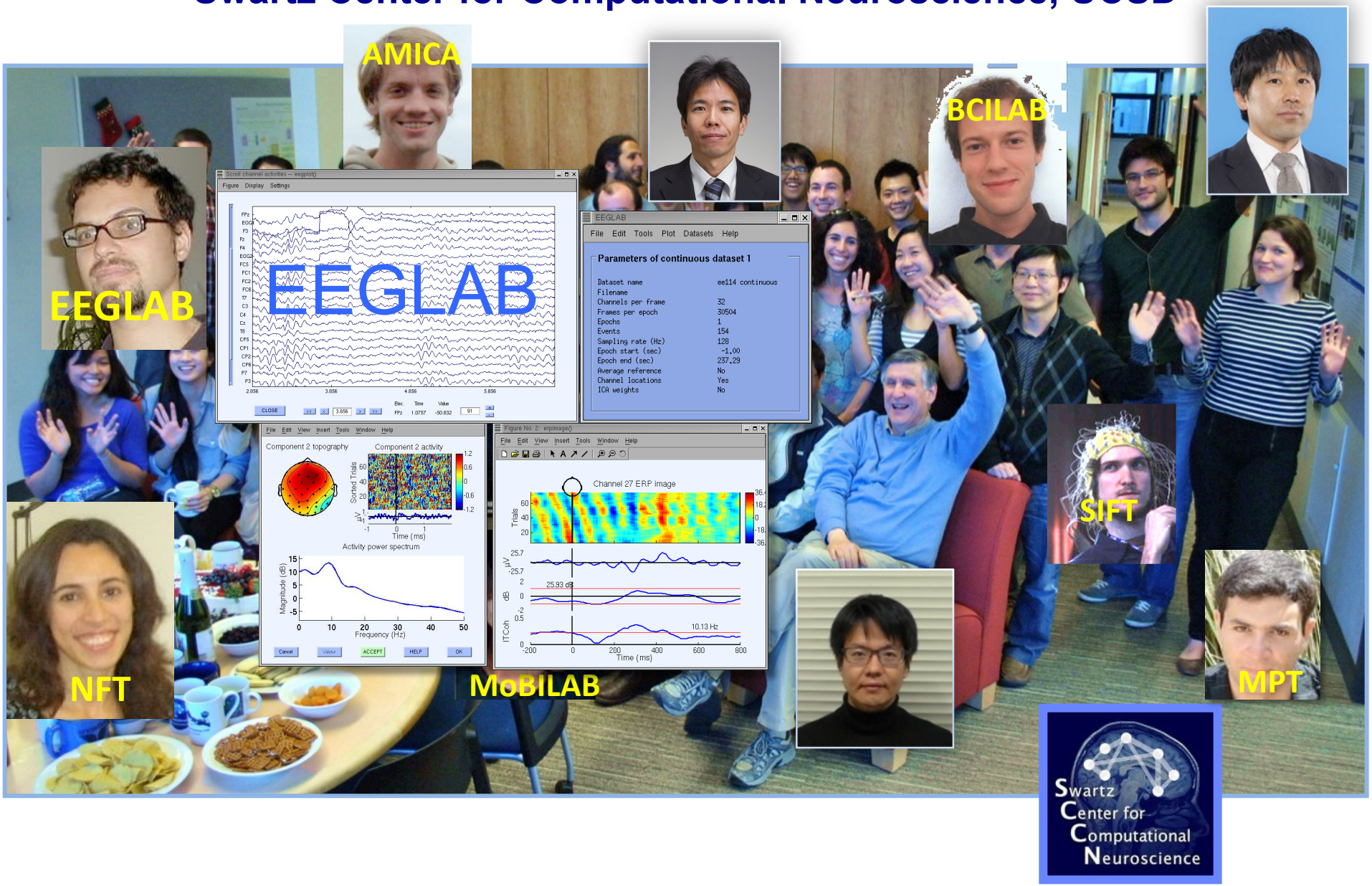
William Blake

Mining Event-related Brain Dynamics I

Scott Makeig
Institute for Neural Computation
University of California San Diego

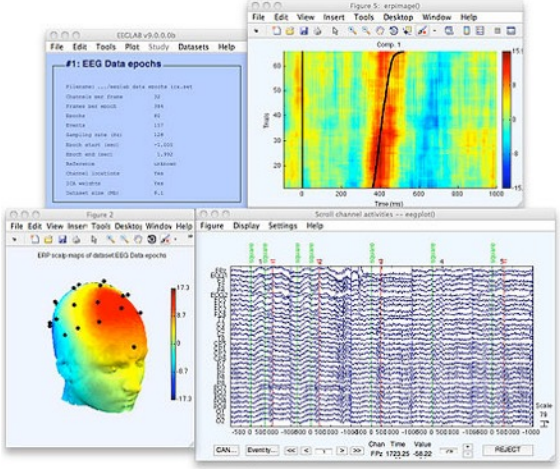
33rd EEGLAB Workshop
Aspet, France
July 4, 2023

Swartz Center for Computational Neuroscience, UCSD



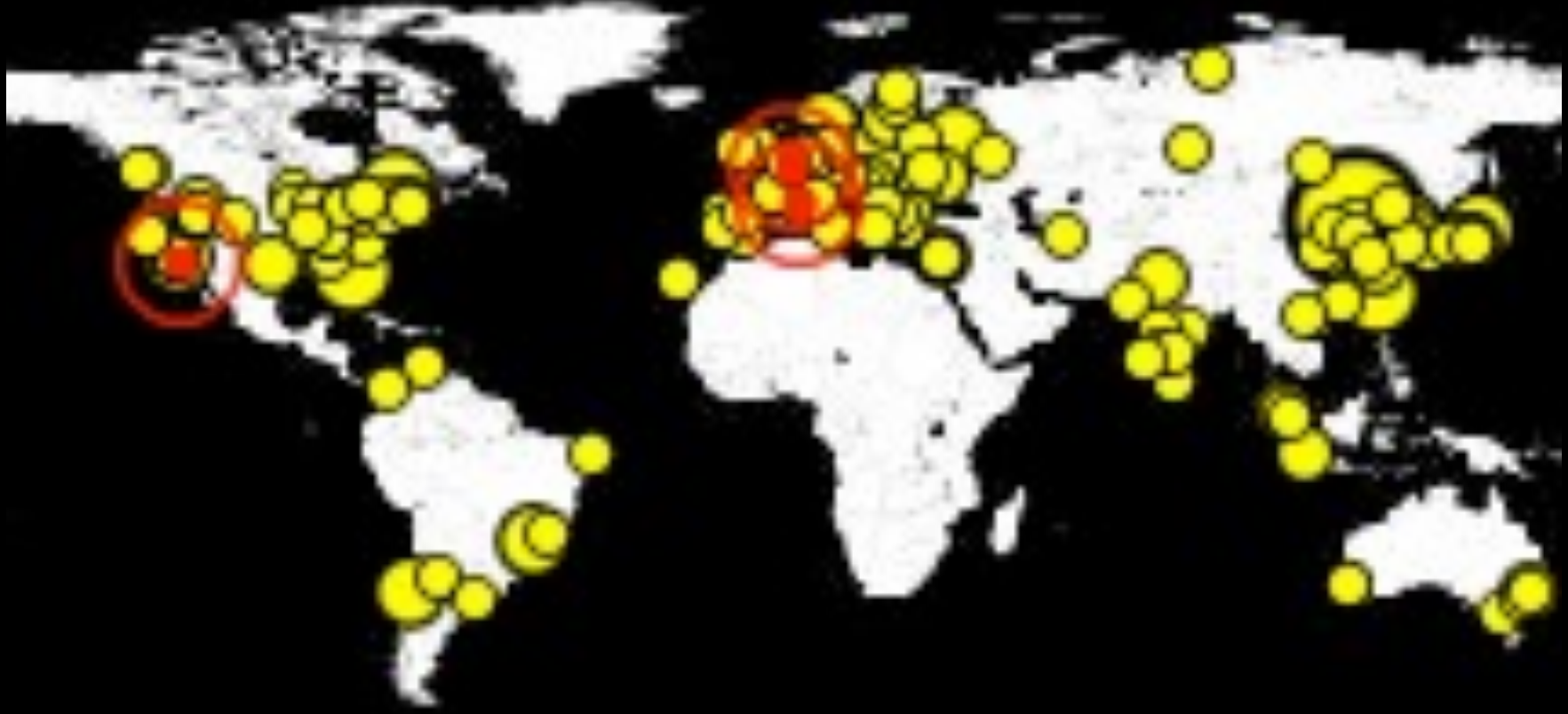
10th Anniversary SCCN Impromptu celebration 1/2/12

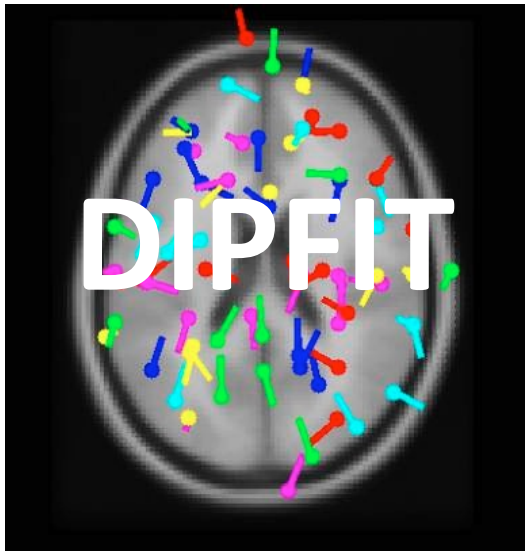
EEGLAB History



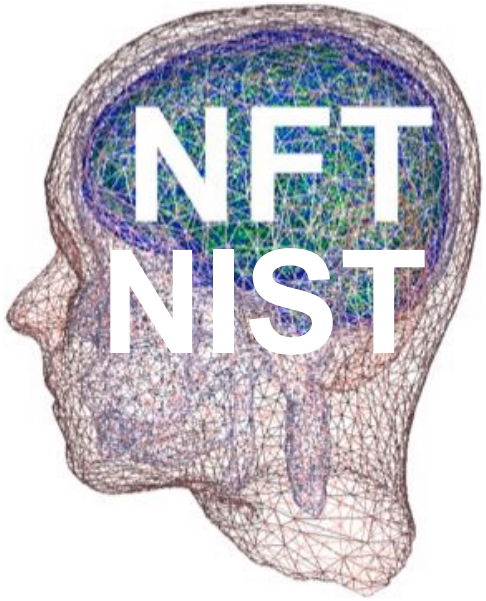
- 1993 – ERSP (Makeig)
- 1995 – Infomax ICA for EEG (Makeig, Bell, Jung, Sejnowski)
- **1997 - EEG/ICA Toolbox (cnl.salk.edu), ITC & ERC**
- 1999 - ERP-image plotting (Jung & Makeig)
- **2000 –GUI design & name 'EEGLAB' (Delorme)**
- **2002 – 1st EEGLAB (sccn.ucsd.edu)**
- **2004 - 1st EEGLAB support 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 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).**
- 2020 – EEGLAB 2019, BIDS integration, ICLabel, get_chanlocs, …
- 2022 -- HED tools, NEMAR, ……

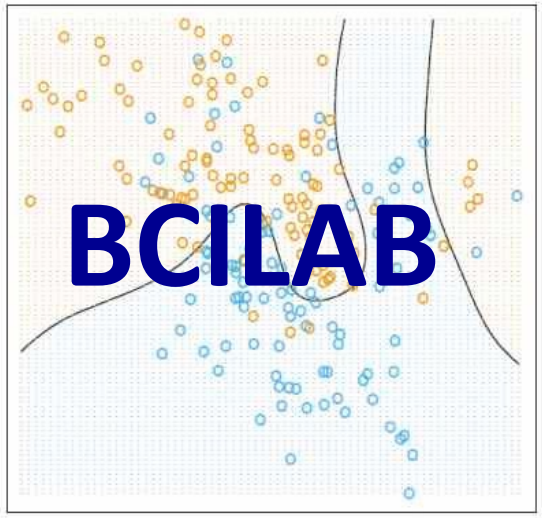
EEGLAB Site Visits (in 24 hours)

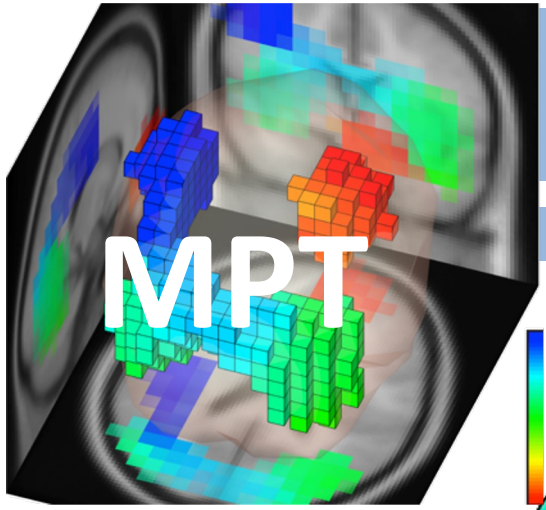


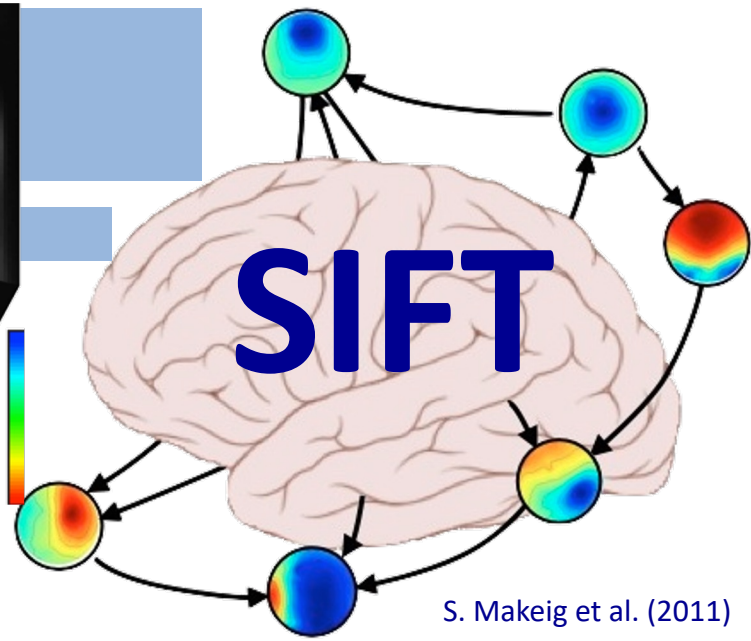


EEGLAB Plug-In Extensions









S. Makeig et al. (2011)

List of data import extensions

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. Hillen	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

EEG as Functional Brain Imaging

Hemodynamic imaging

= imaging local brain **Energy**

Direct 3-D inverse model,

but quite slow & indirect

as well as expensive,

very heavy & non-portable.

1993 -

Electromagnetic imaging

= imaging

local cortical* field *synchrony

3-D imaging needs head model,

but a quite fast & direct measure

of *one aspect* of cortical activity –

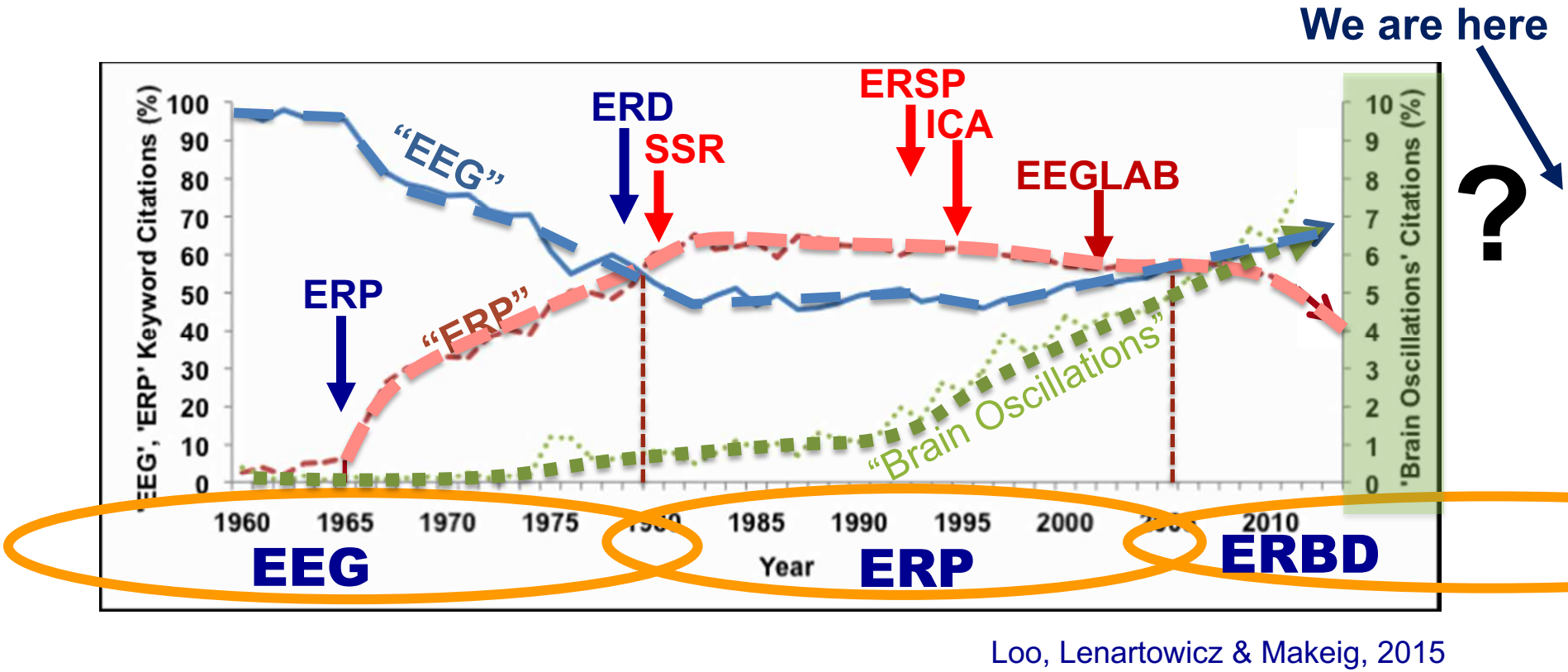
local spatial field coherence.

1926 -

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

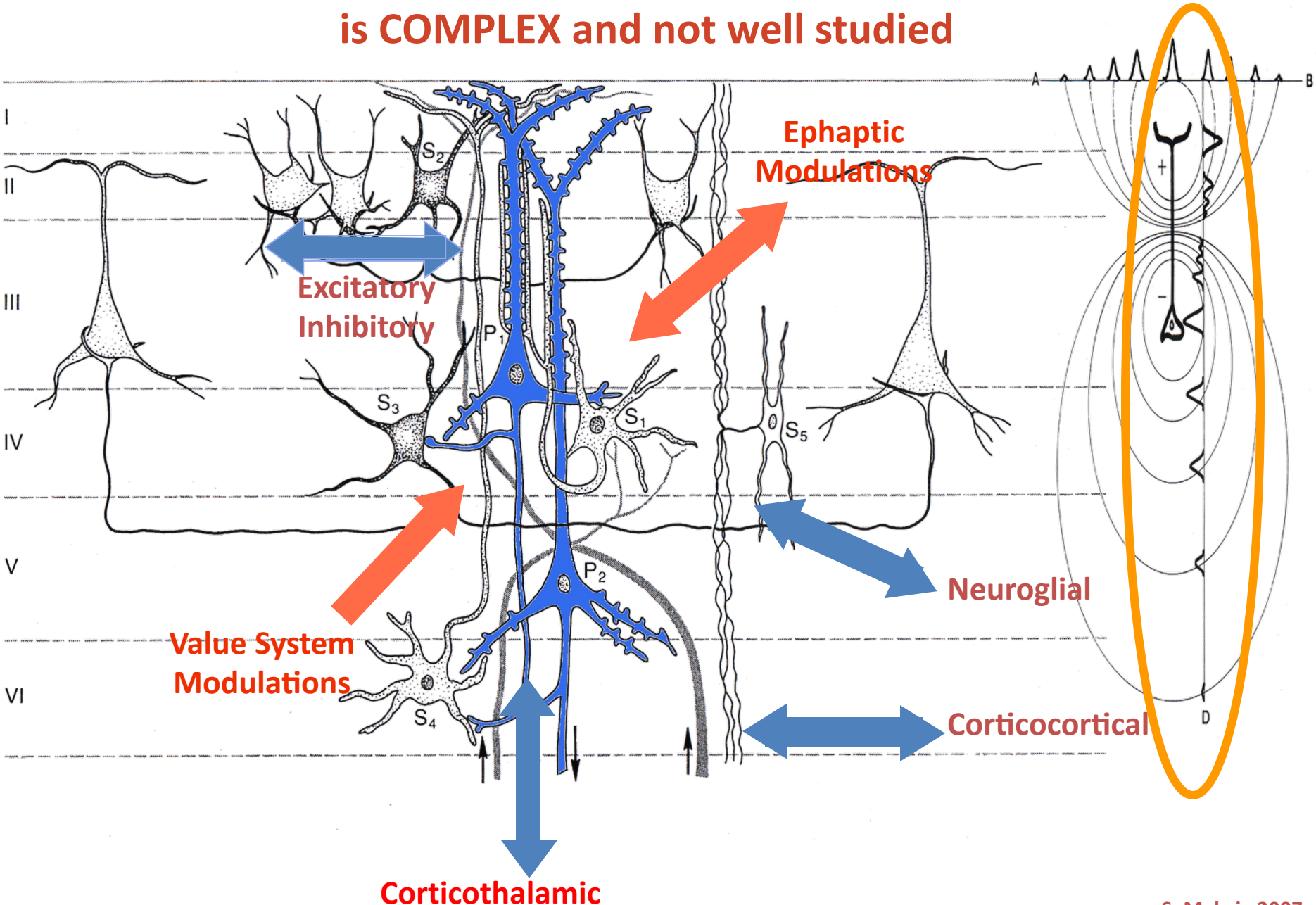
What is EEG?

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

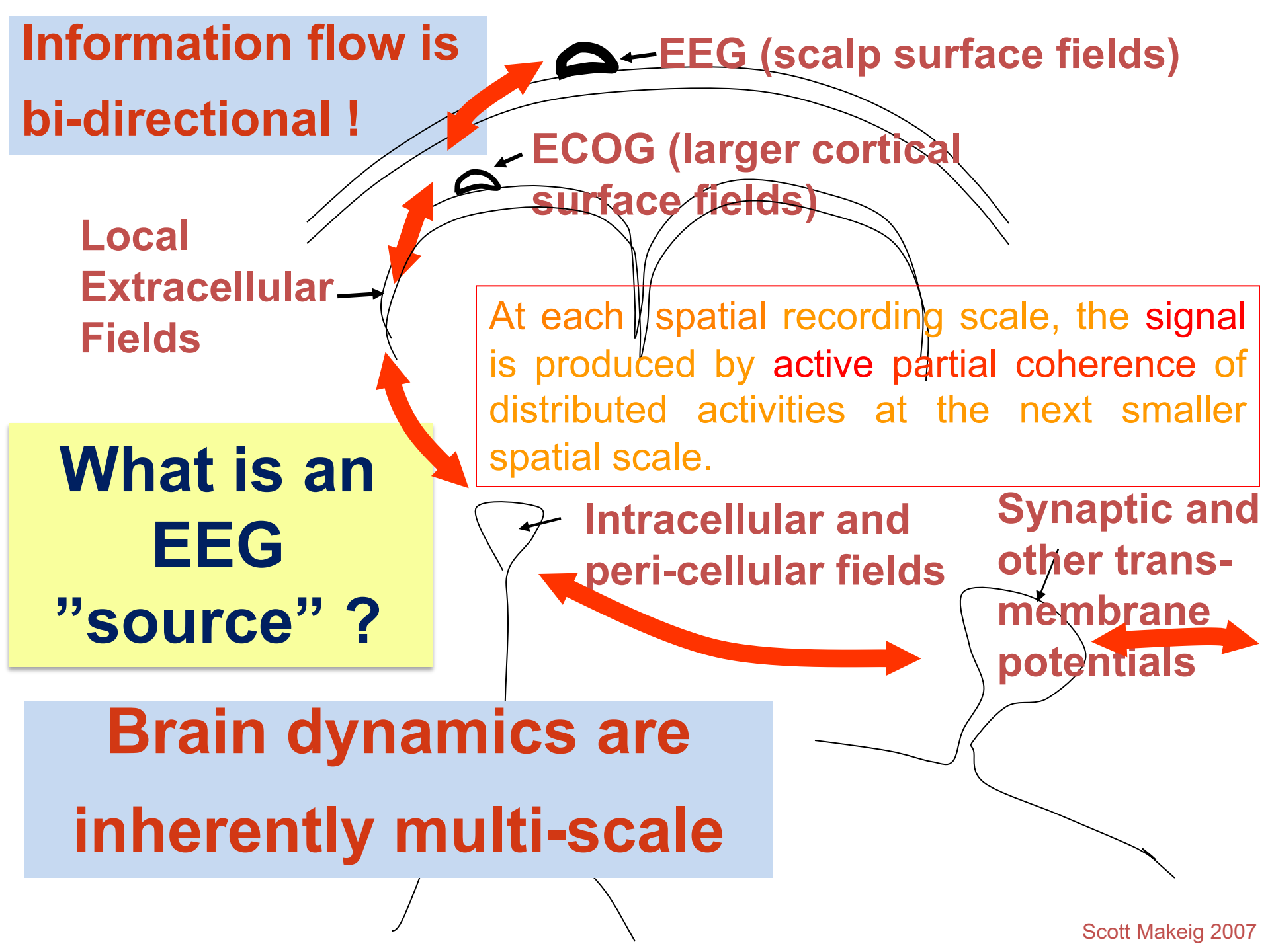
- **But *which* portion?**
- **Triggered and modulated *how*?**
- **With *what* functional significance?**

Cloud art: Berndnaut

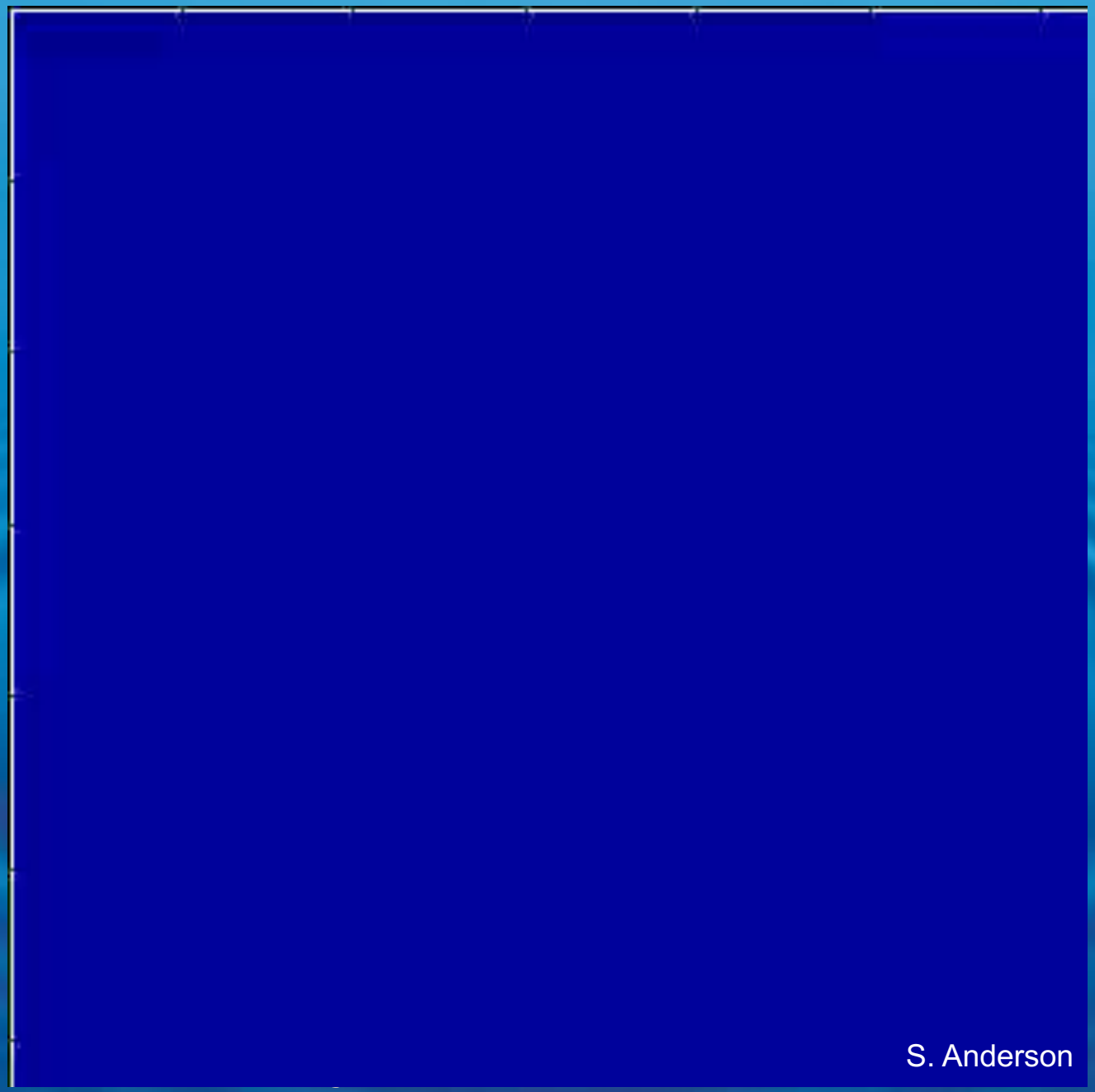
The generation and modulation of local field potentials is COMPLEX and not well studied



S. Makeig 2007


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 "source" ?
Intracellular and peri-cellular fields
Synaptic and other trans-membrane potentials
Brain dynamics are inherently multi-scale
Scott Makeig 2007

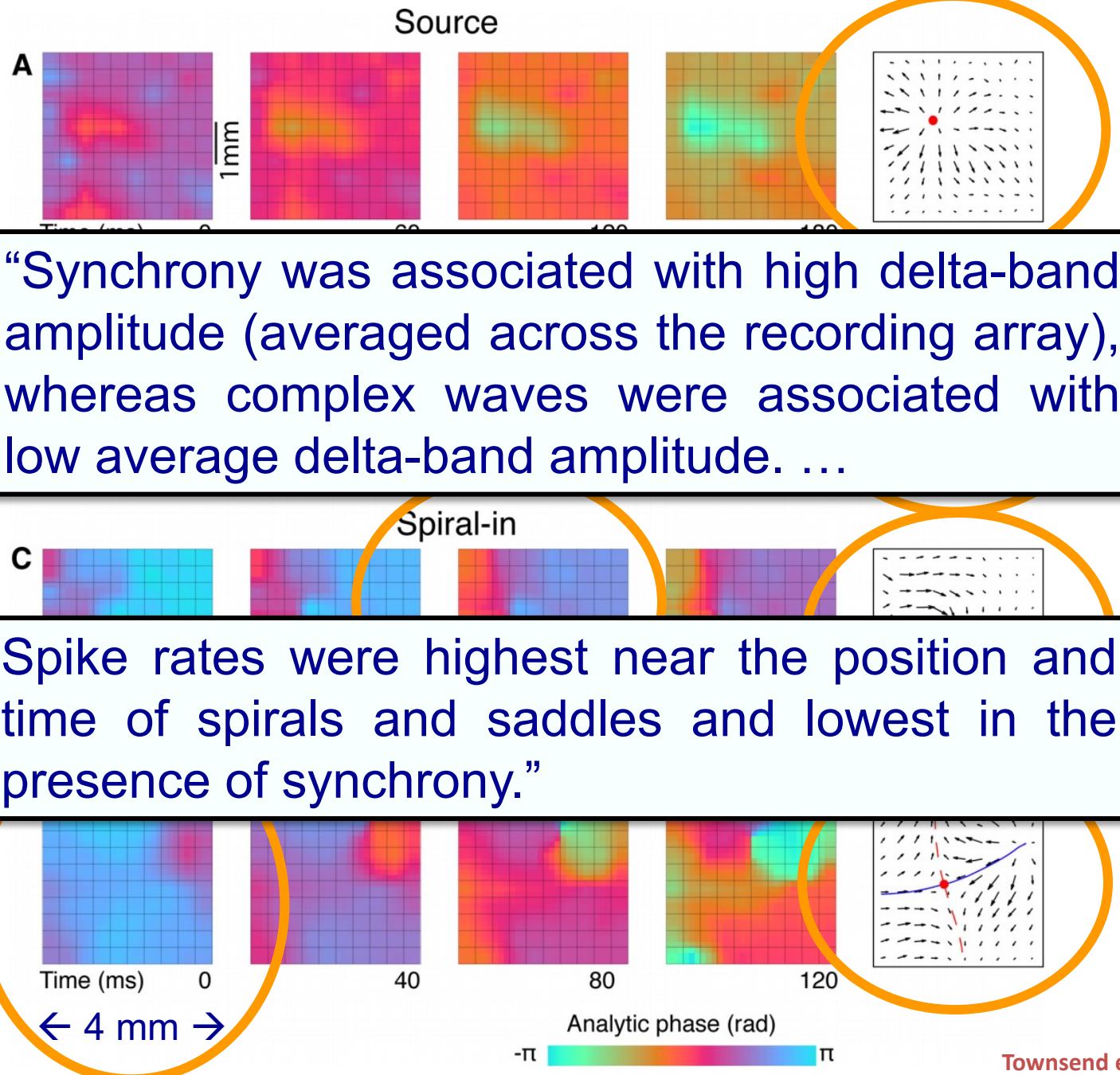
Phase cones (Freeman)



RS Anderson, 2007

J. Neurosci., March 18, 2015 • 35(11):4657–4662

Delta band (1-4 Hz) in anesth. animals



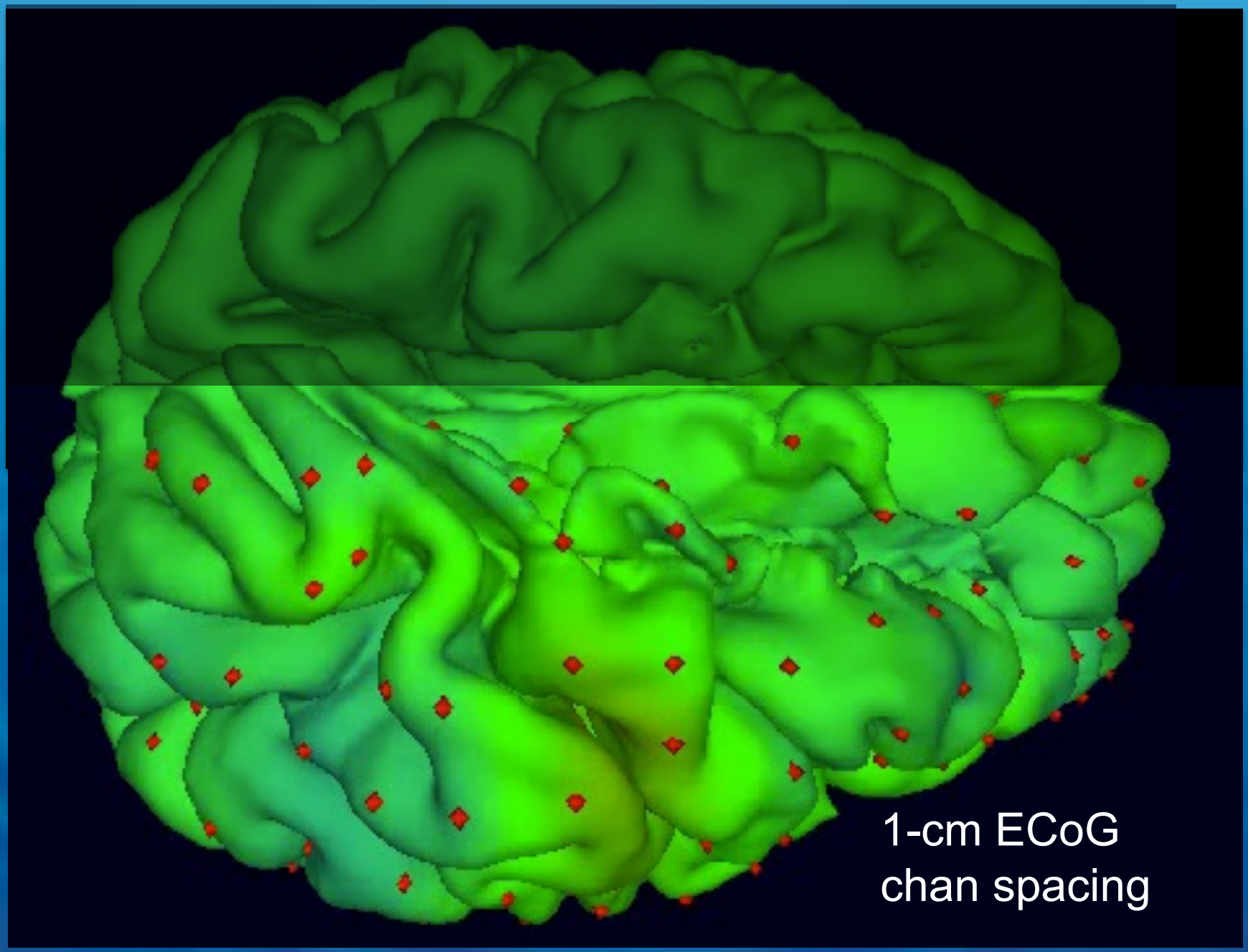
"Synchrony was associated with high delta-band amplitude (averaged across the recording array), whereas complex waves were associated with low average delta-band amplitude. …

Spike rates were highest near the position and time of spirals and saddles and lowest in the presence of synchrony."

Simple patterns

Complex patterns

Townsend et al., 2015



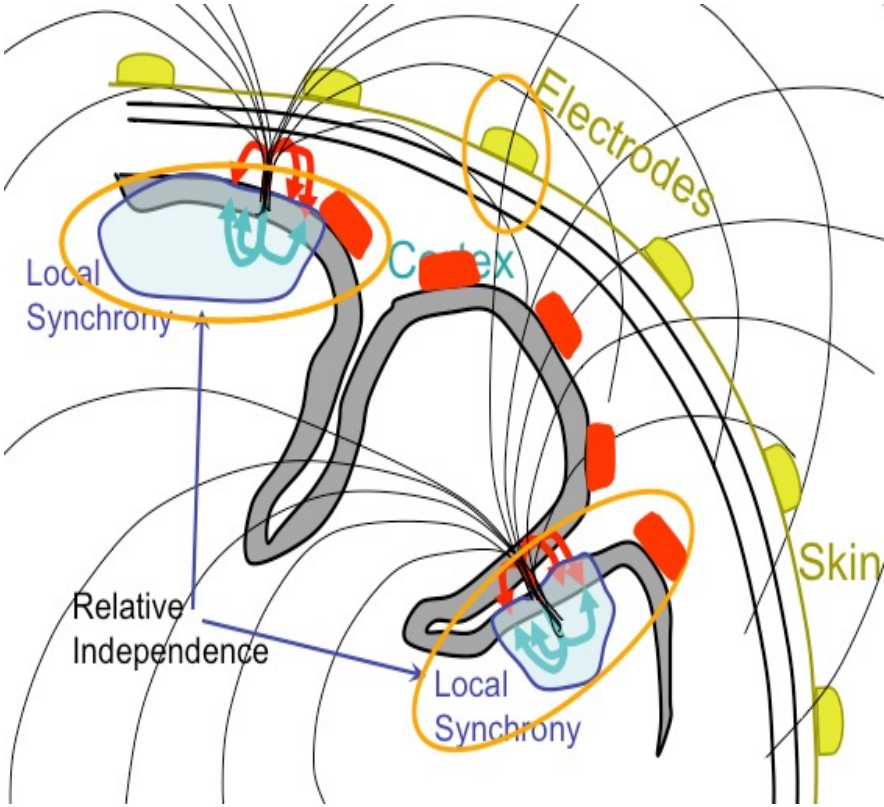
Z Akalin Acar, 2017

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

1-mm ECoG
chan spacing

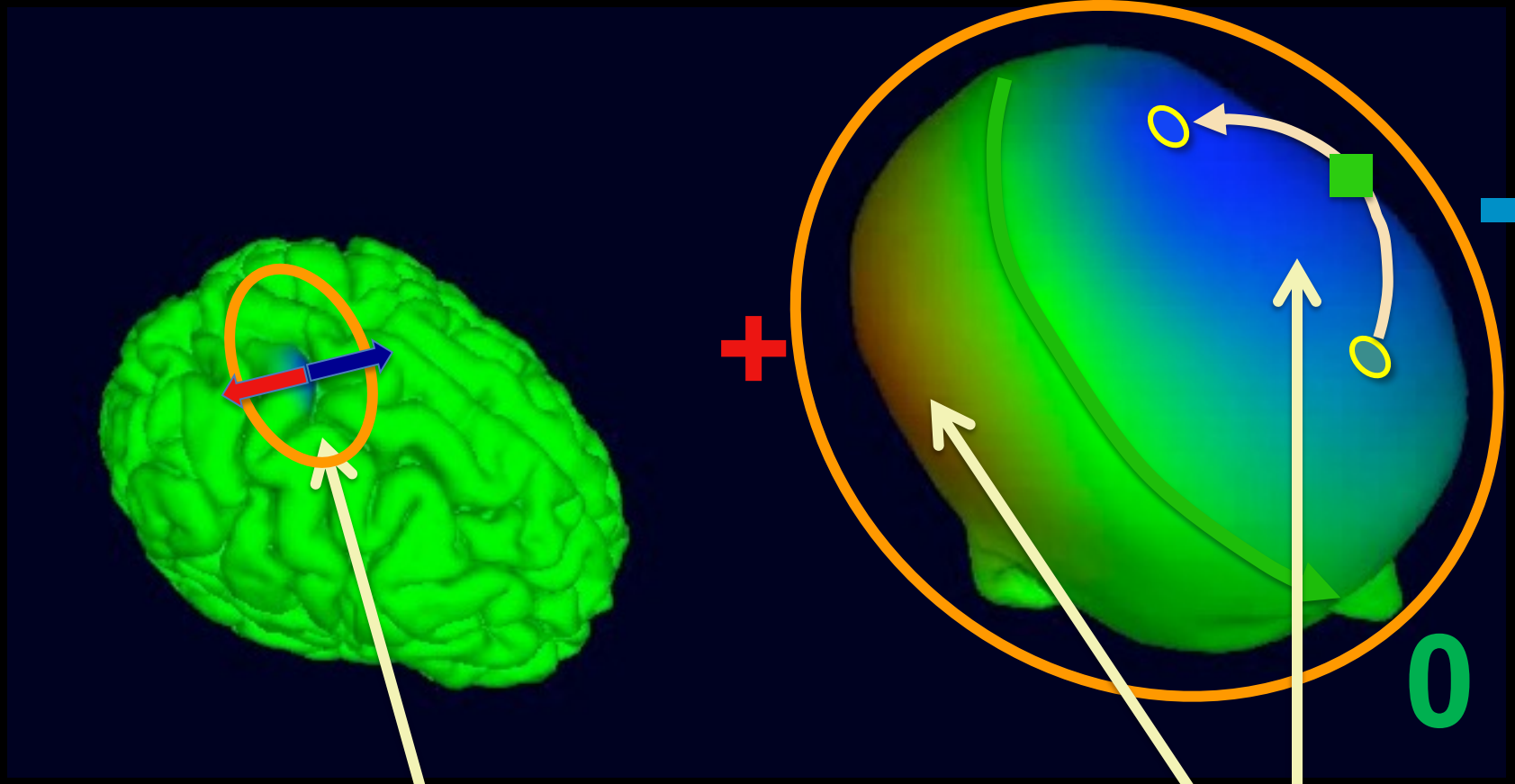
Naïve 2-D interpretation of EEG signals?

Cortical EEG signal projection patterns as point processes



Cortical source current volume conduction patterns

The very broad EEG point-spread function

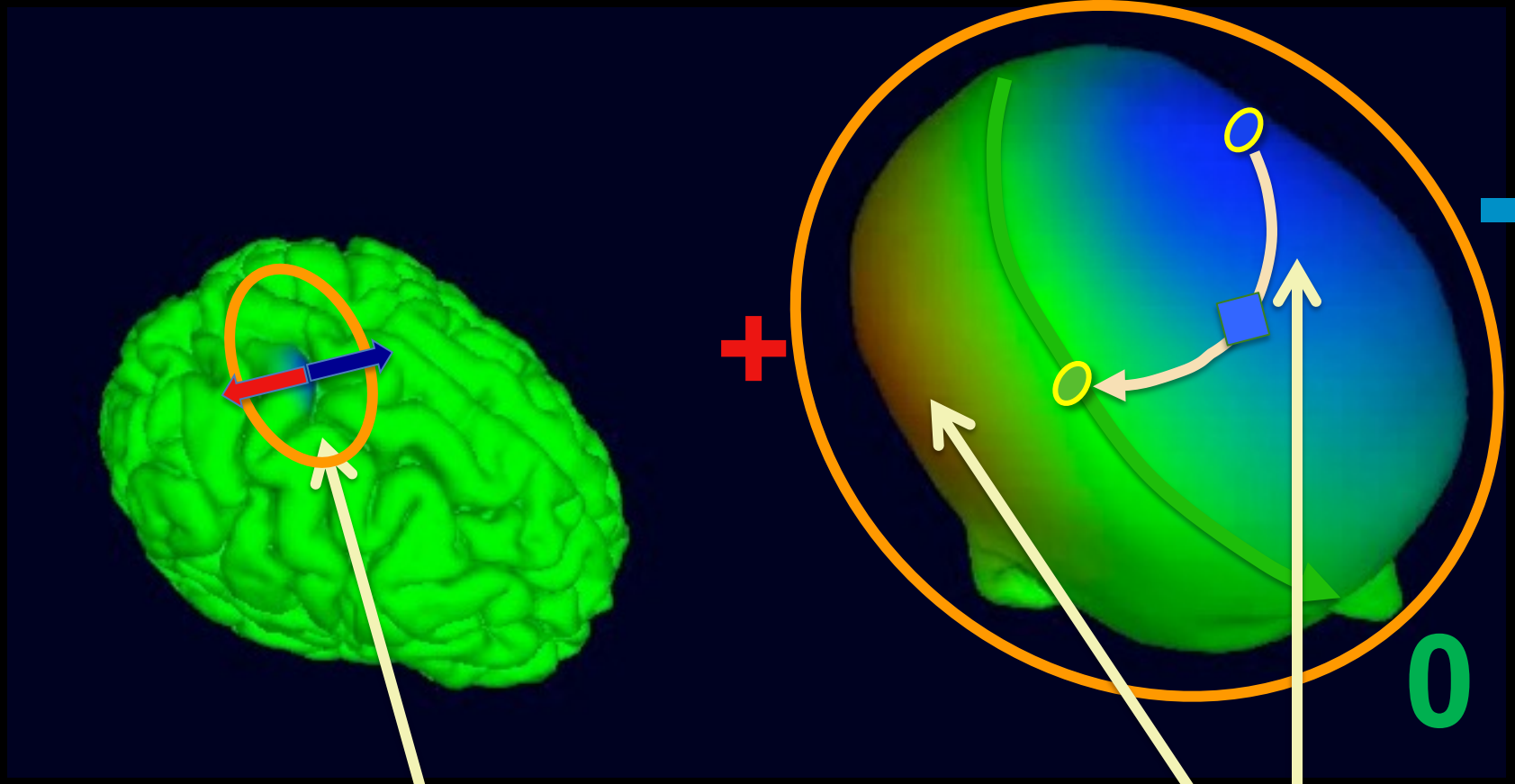


Single simulated parietal source →

Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The very broad EEG point-spread function



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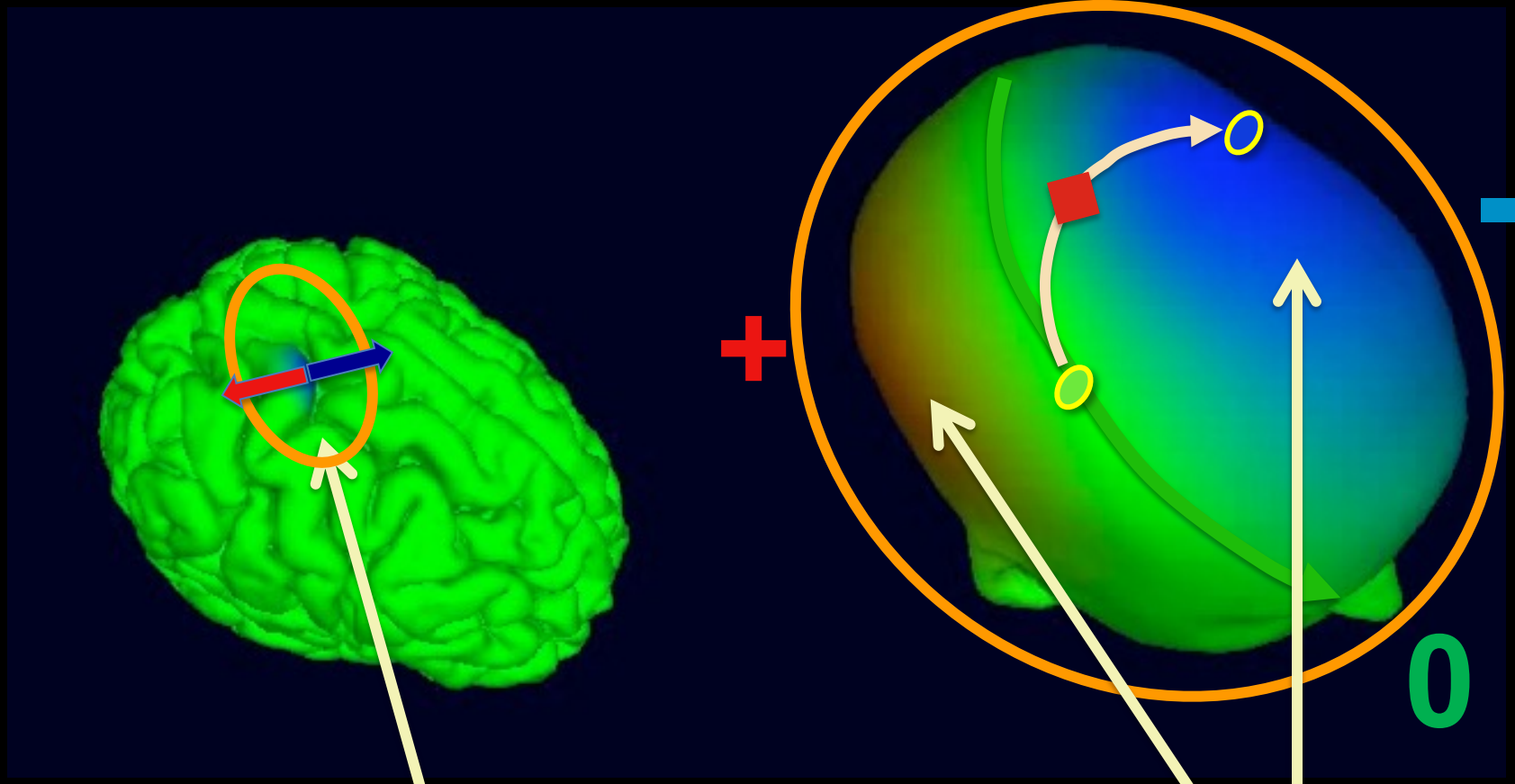

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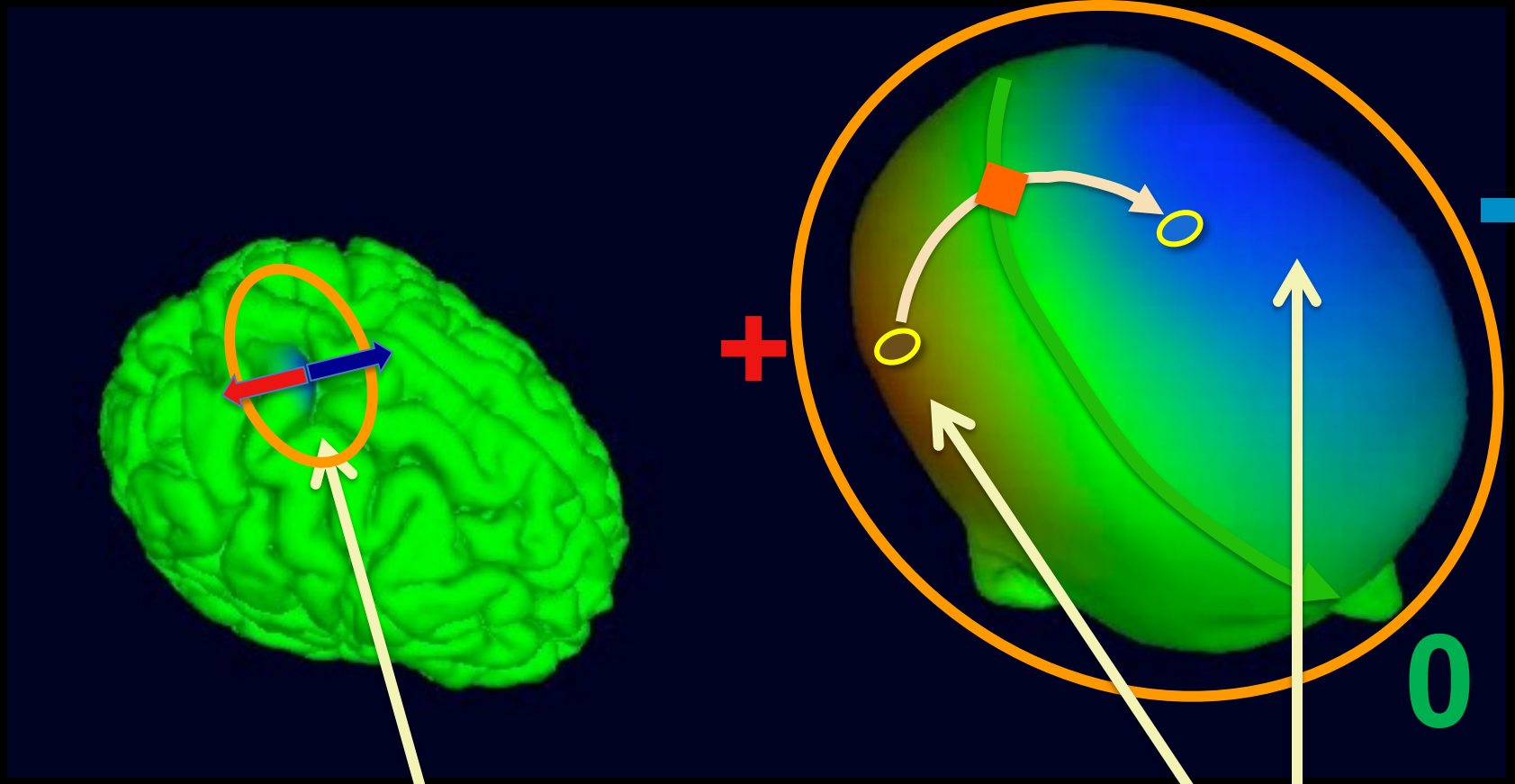
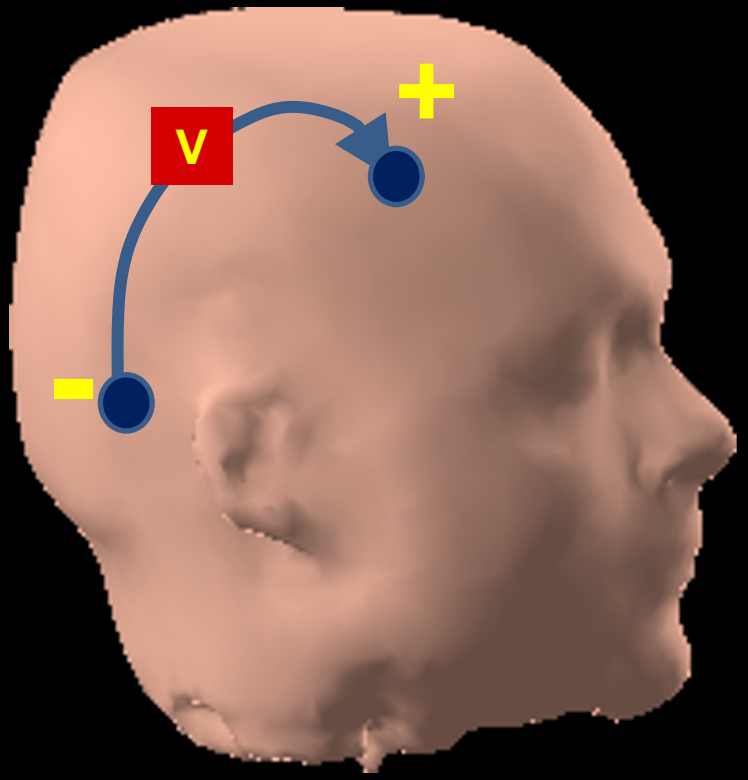


Single simulated parietal source →

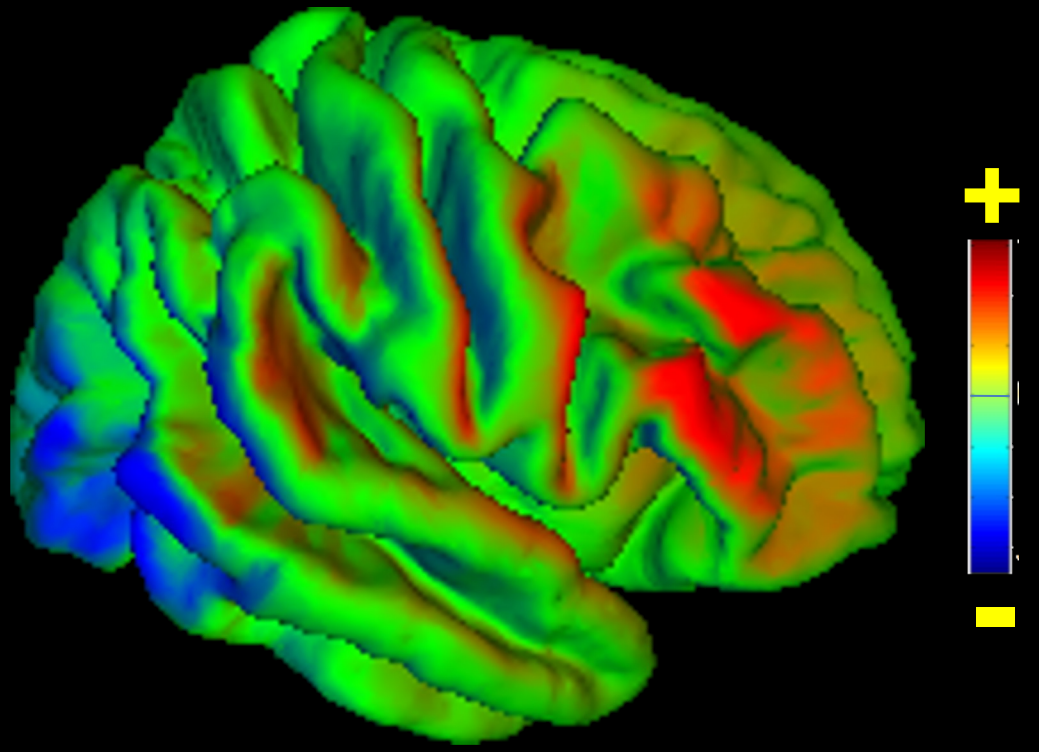
Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The ‘receptive field’ of a bipolar EEG channel



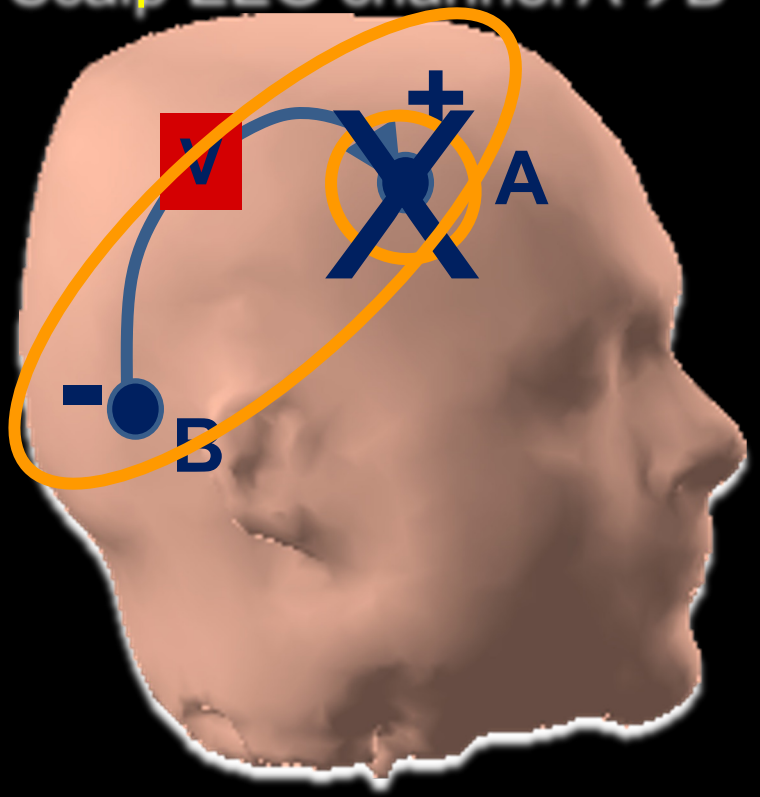
Scalp EEG channel

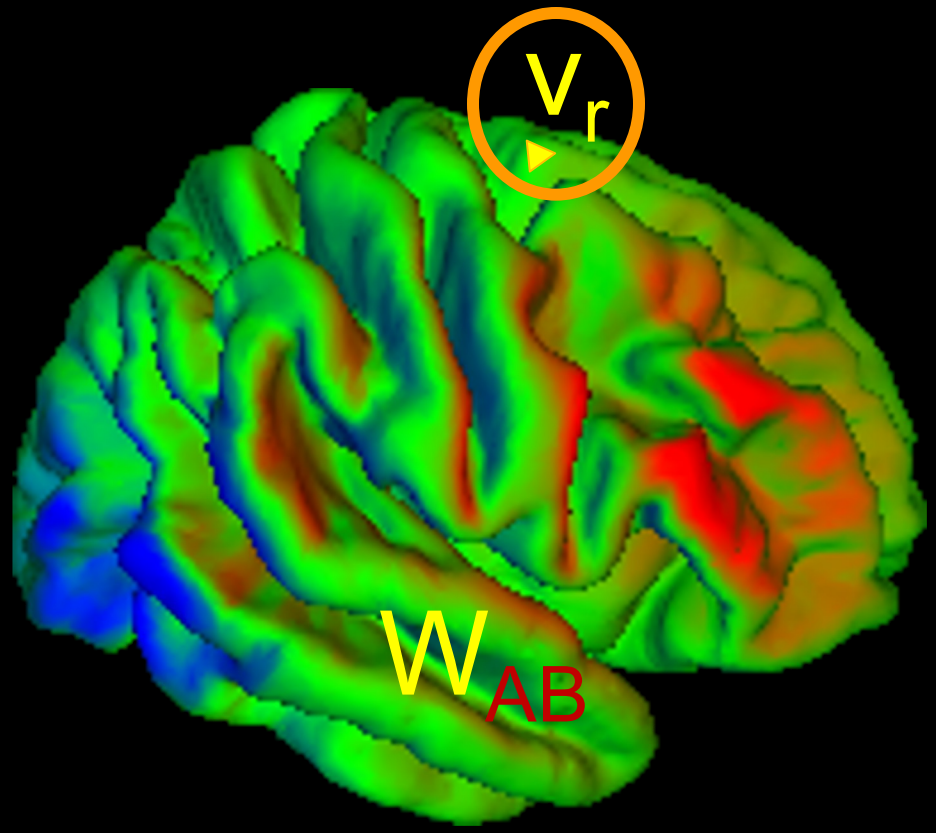


Its cortical ‘receptive field’

The ‘receptive field’ of a bipolar EEG channel!

Scalp EEG channel A→B

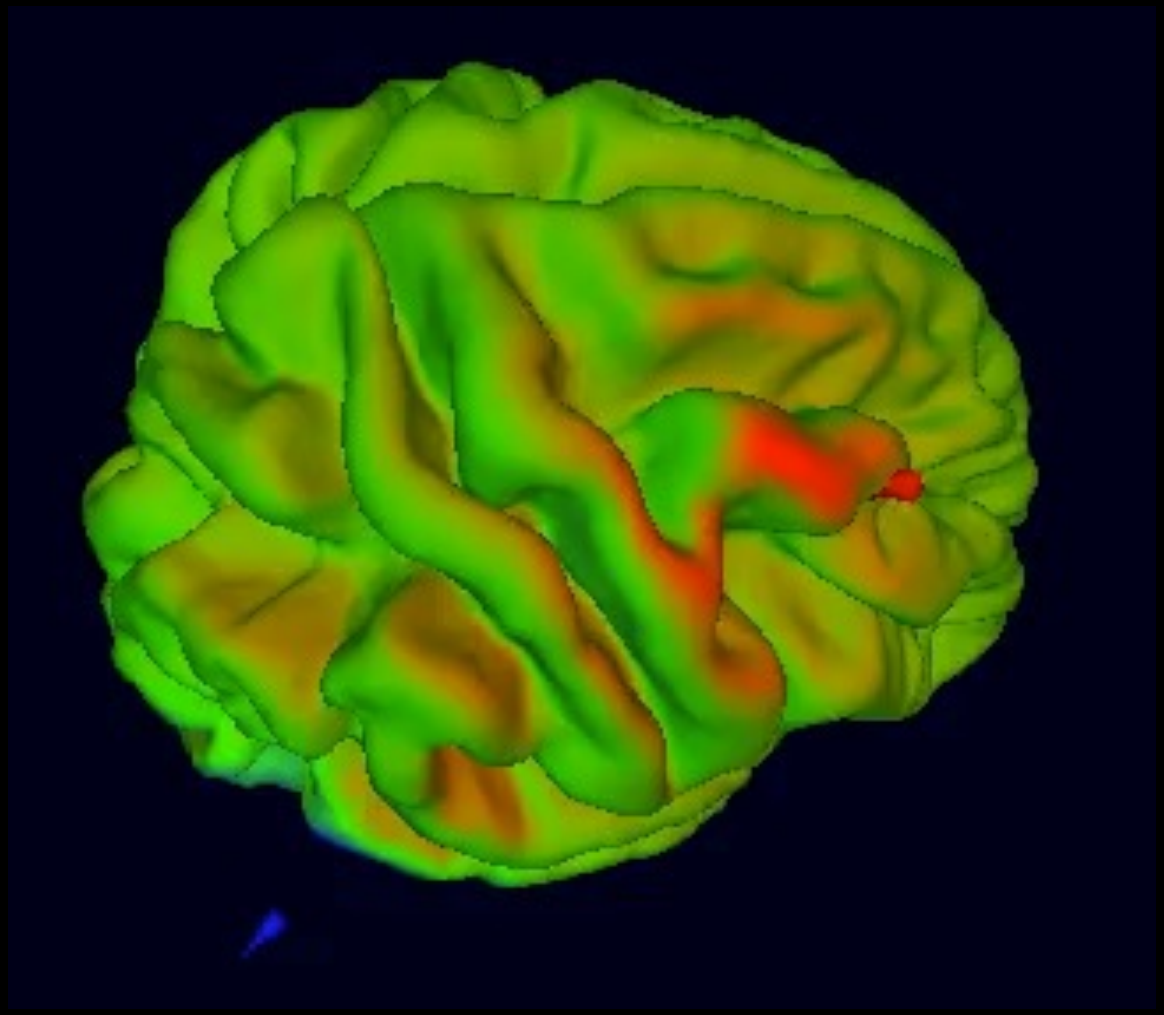




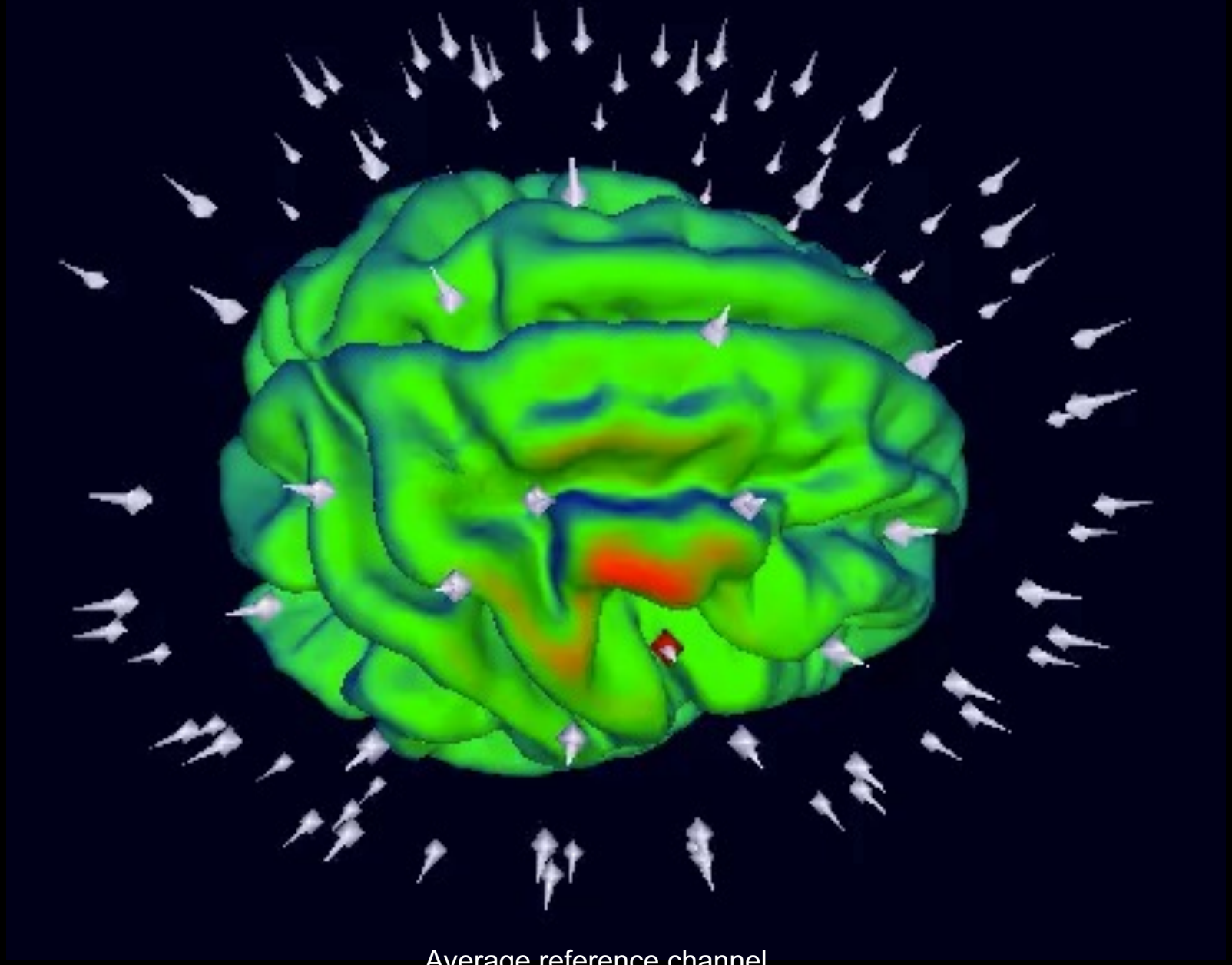
Its cortical ‘receptive field’

At time t,

$$V^{(t)}_{A\to B} = \sum_{r \text{ in Cortex}} v_r \times W_{AB}(r)$$

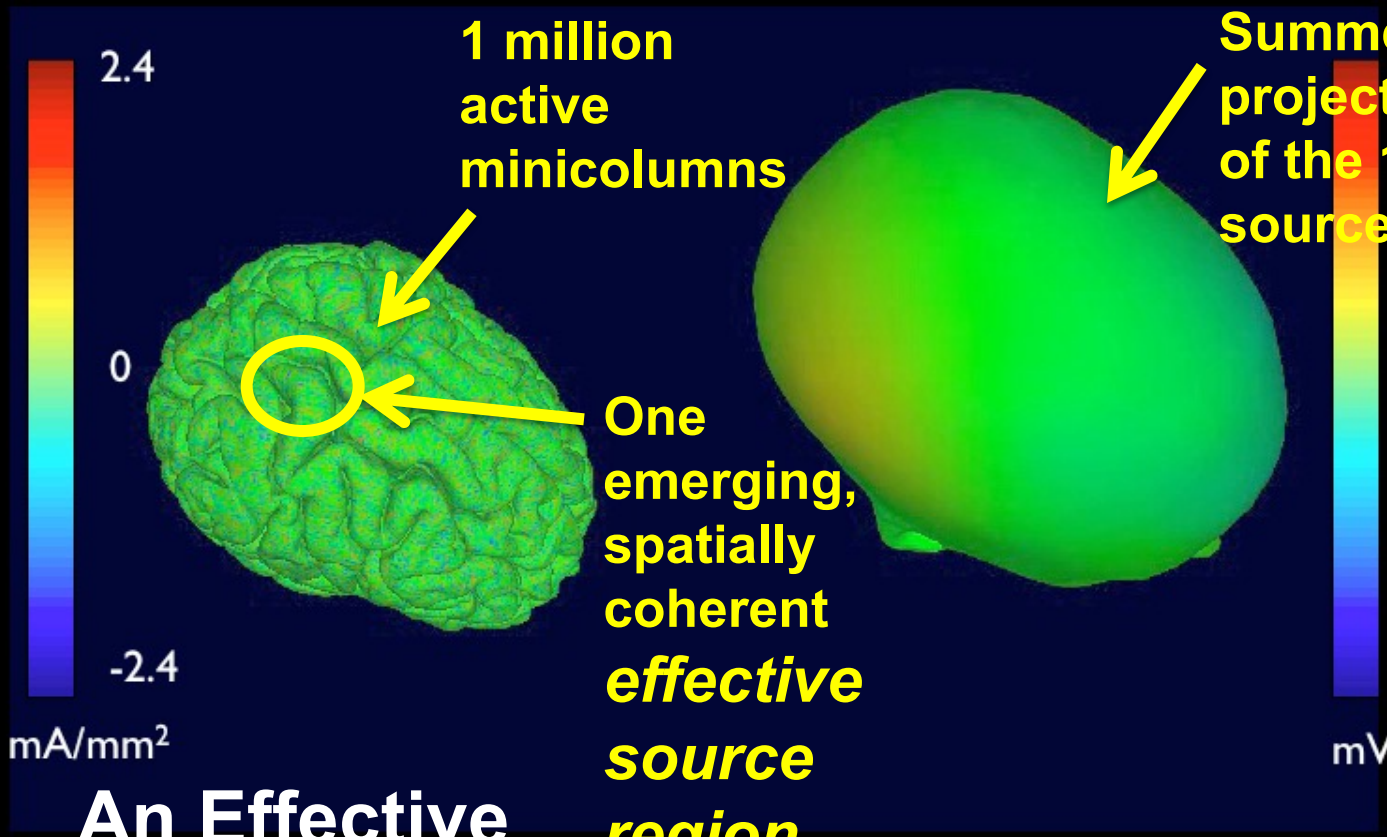


Bipolar channel

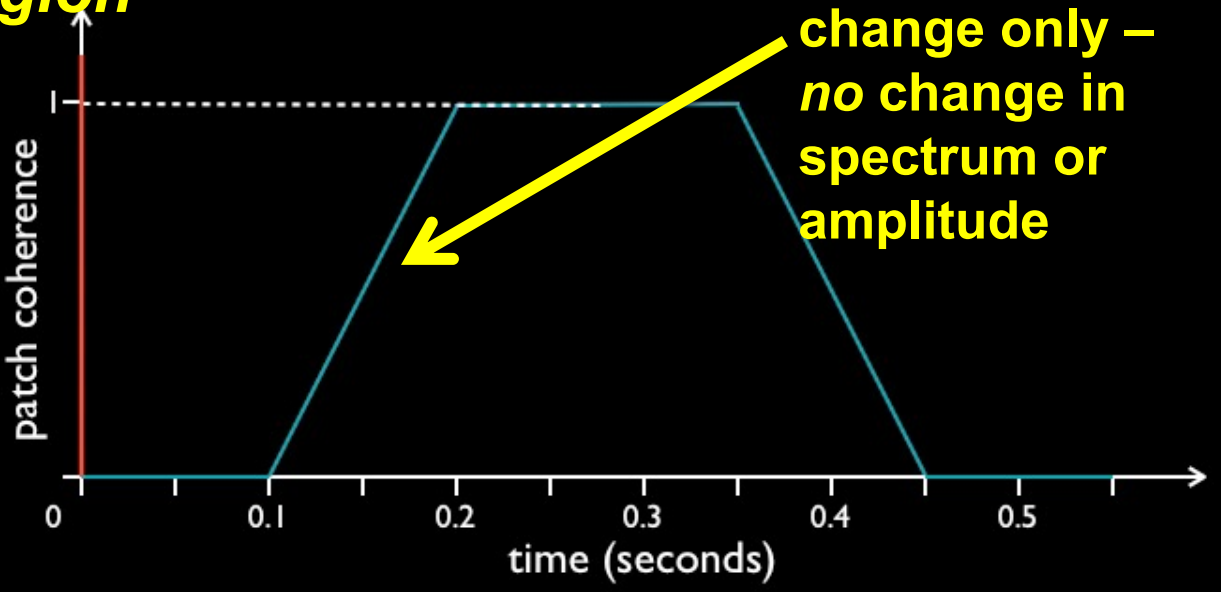


Average reference channel

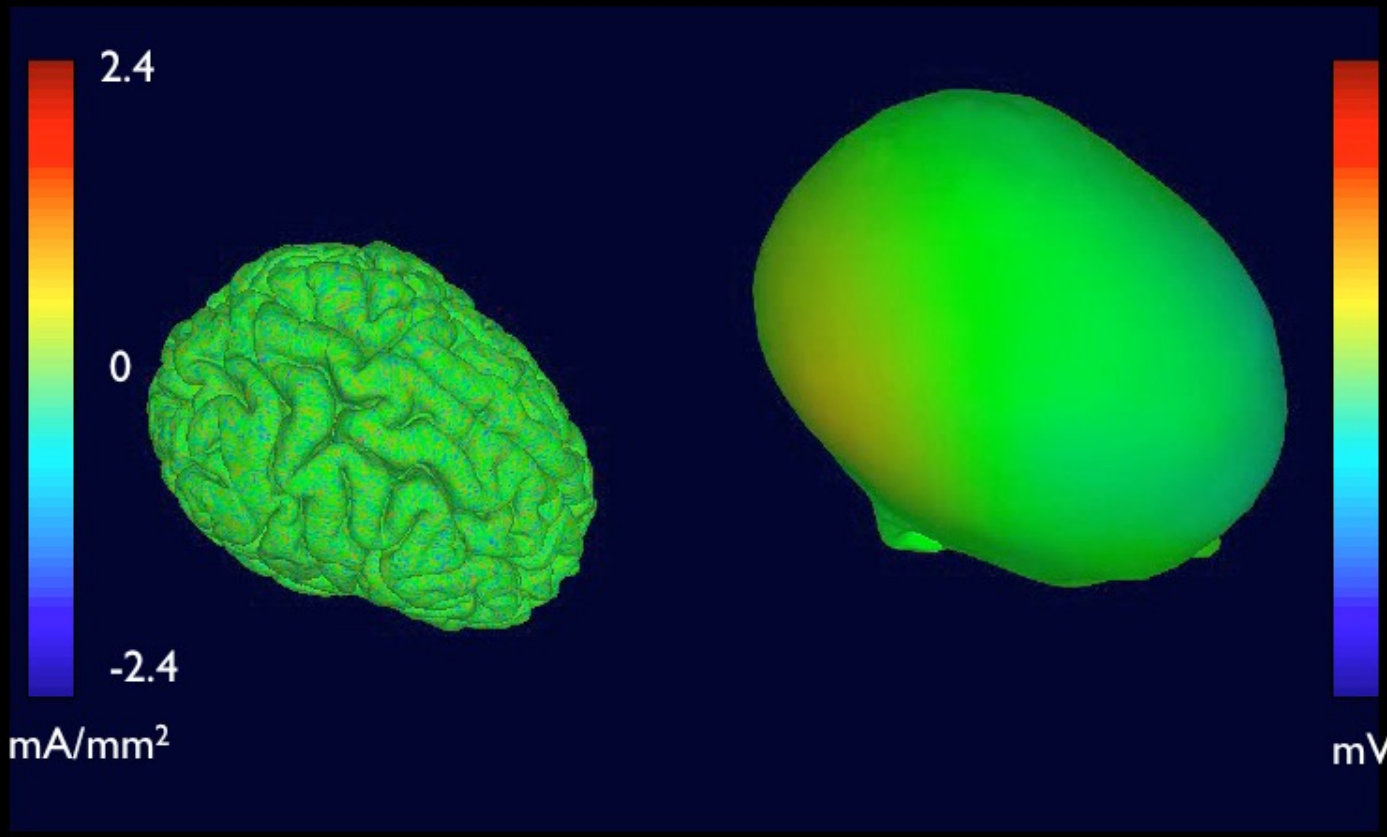
Phase cones (Freeman)

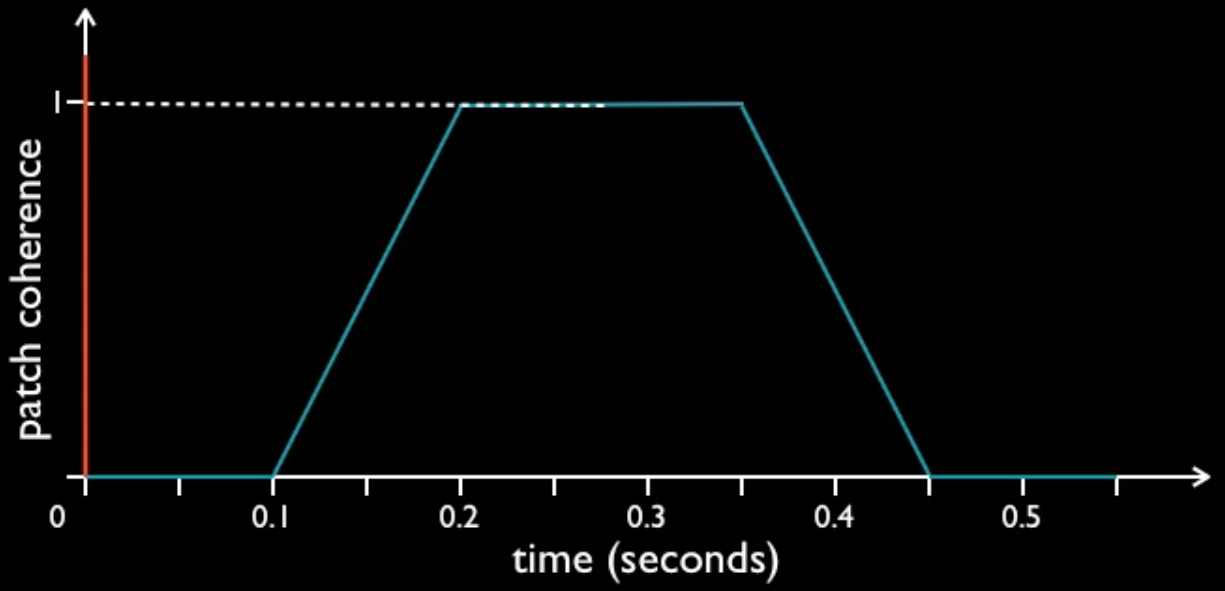


An Effective EEG Source



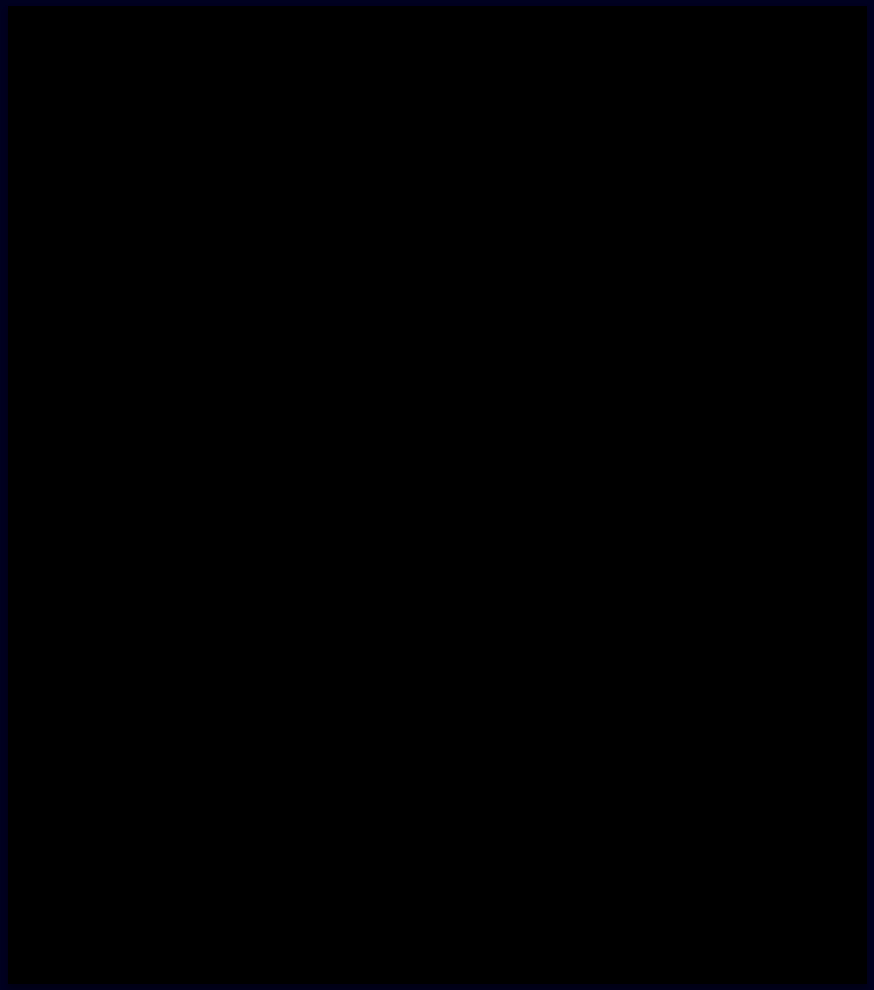
Z. Akalin Acar & S. Makeig (2015)

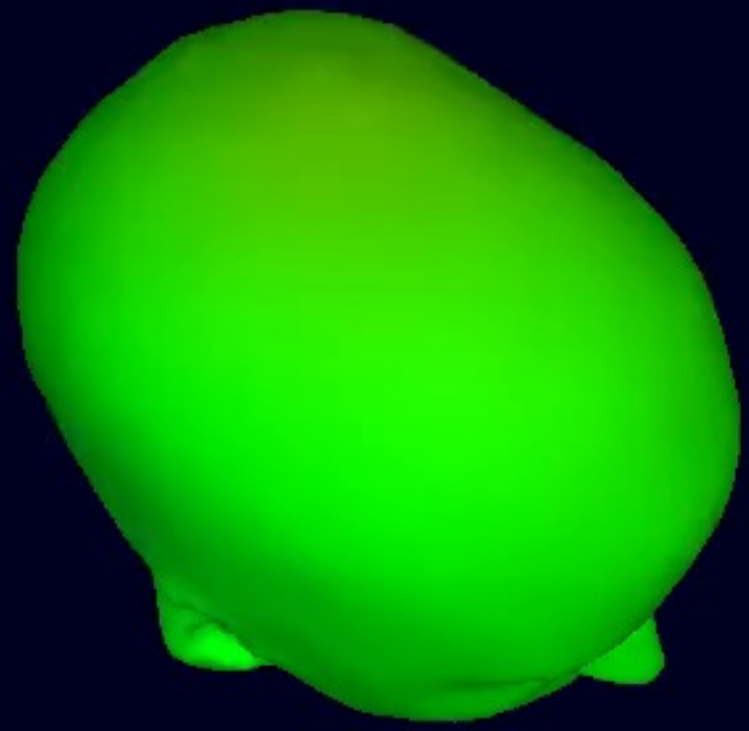




Z. Akalin Acar & S. Makeig (2015)

Here, what are the cortical ‘effective sources’?



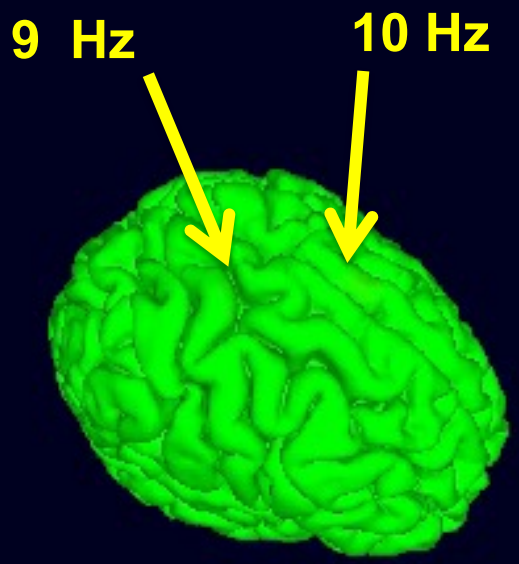


Scalp projection

Z. Akalin Acar & S. Makeig (2012)

Scalp epiphenomena !

Phenomena



Two spatially stationary cortical effective sources

Epiphenomena

epiphenomena --

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

Summed scalp projection

Z. Akalin Acar & S. Makeig (2012)

1 million active minicolumns

Summed scalp projection

2.4

0

-2.4

mA/mm²

0.13

-0.13

mV

One spatially coherent *effective source*

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.

patch coherence

0 0.1 0.2 0.3 0.4 0.5

time (seconds)

Z. Akalin Acar & S. Makeig (2015)


Who
am I?

Embodied Agency

Brain processes

have evolved and function

to optimize the outcomes

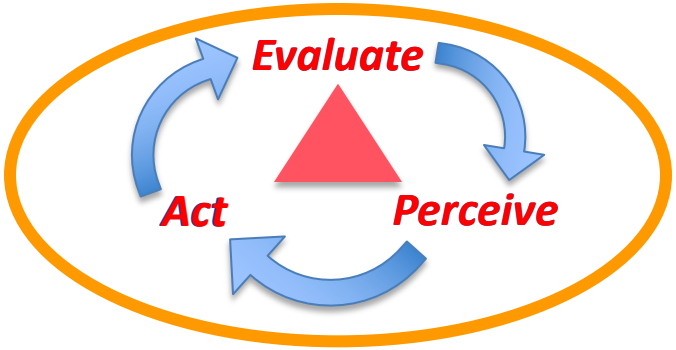
of the ***willed*** *behavior*

the brain organizes

in response to

perceived & felt

challenges and opportunities.



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

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 can be used to learn and monitor
how the brain and nervous system
support human consciousness
in ALL its aspects --

Knowing

Feeling

Willing

S. Makeig (2017)

Electromagnetic source localization using realistic head models

NFT

Solve
for
pro
using
head
(E

T1-weighte

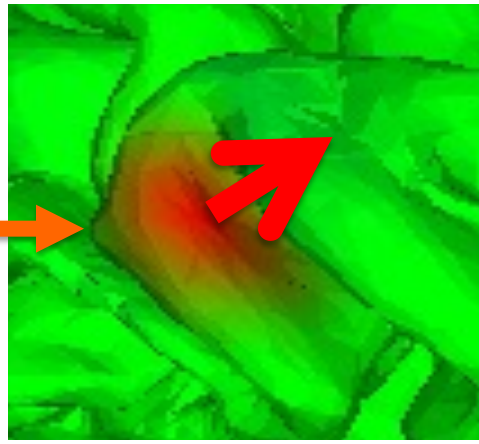
MRI

Proto

Segmentation

Simple Map

Signal Processing



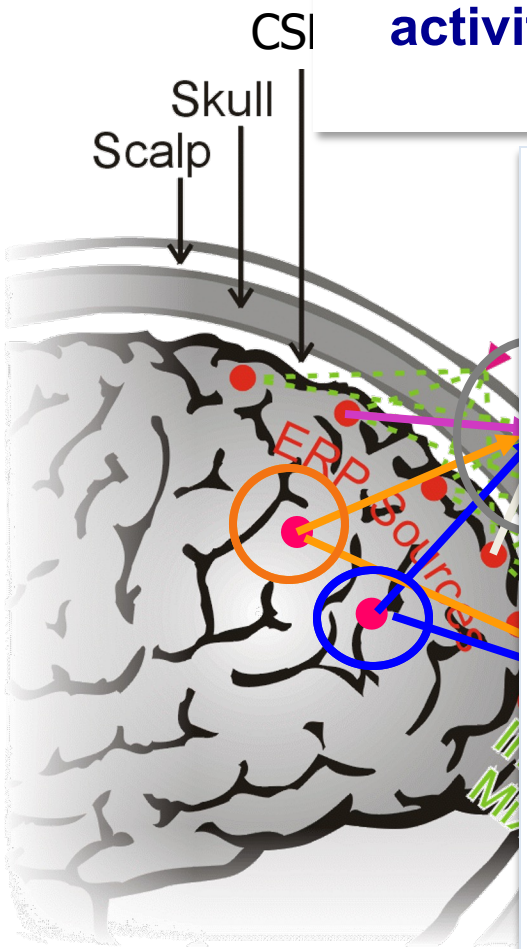
Source Estimate

EEG/MEG

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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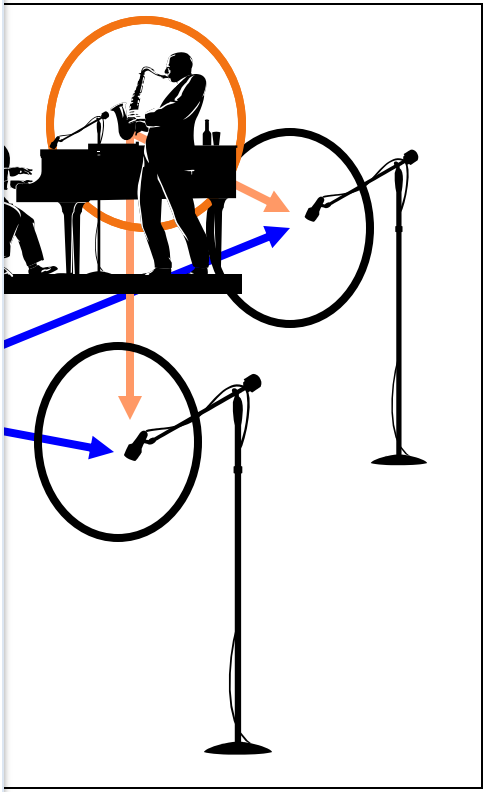
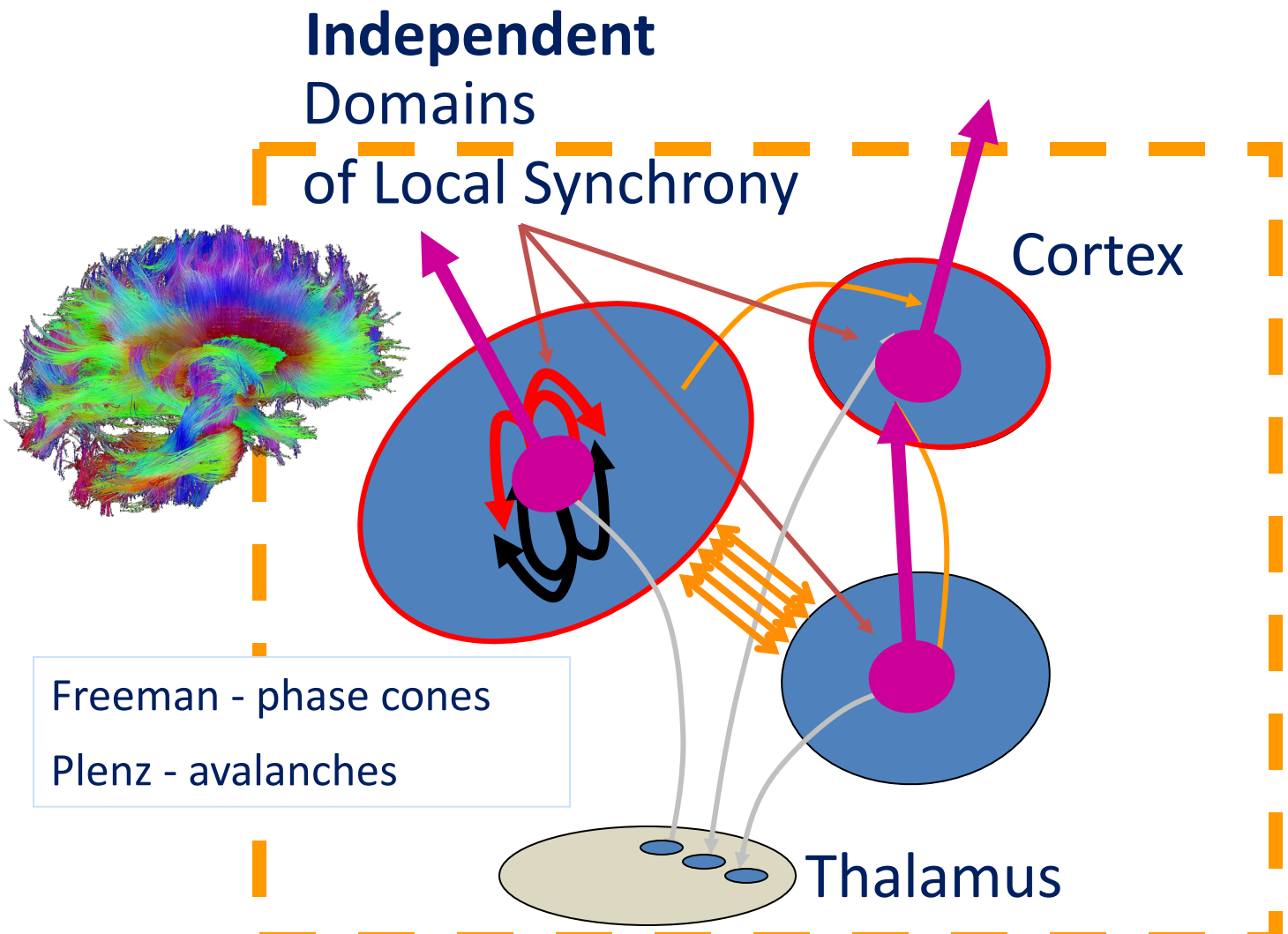
Abstract

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

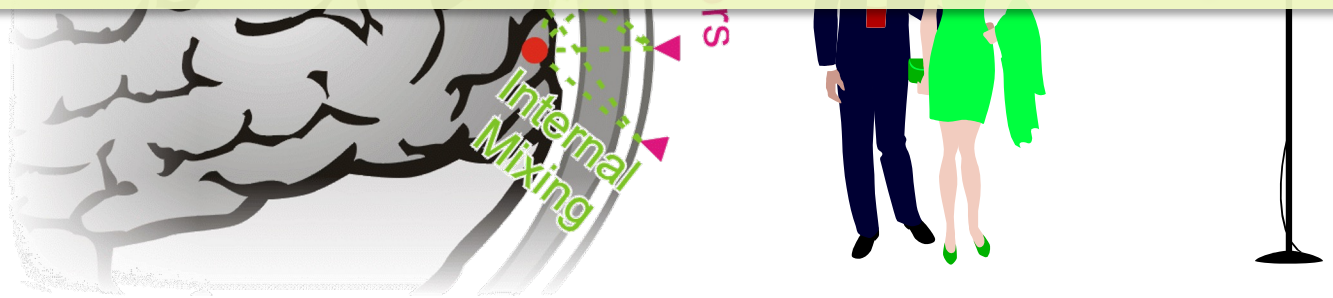
Identification → Localization

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

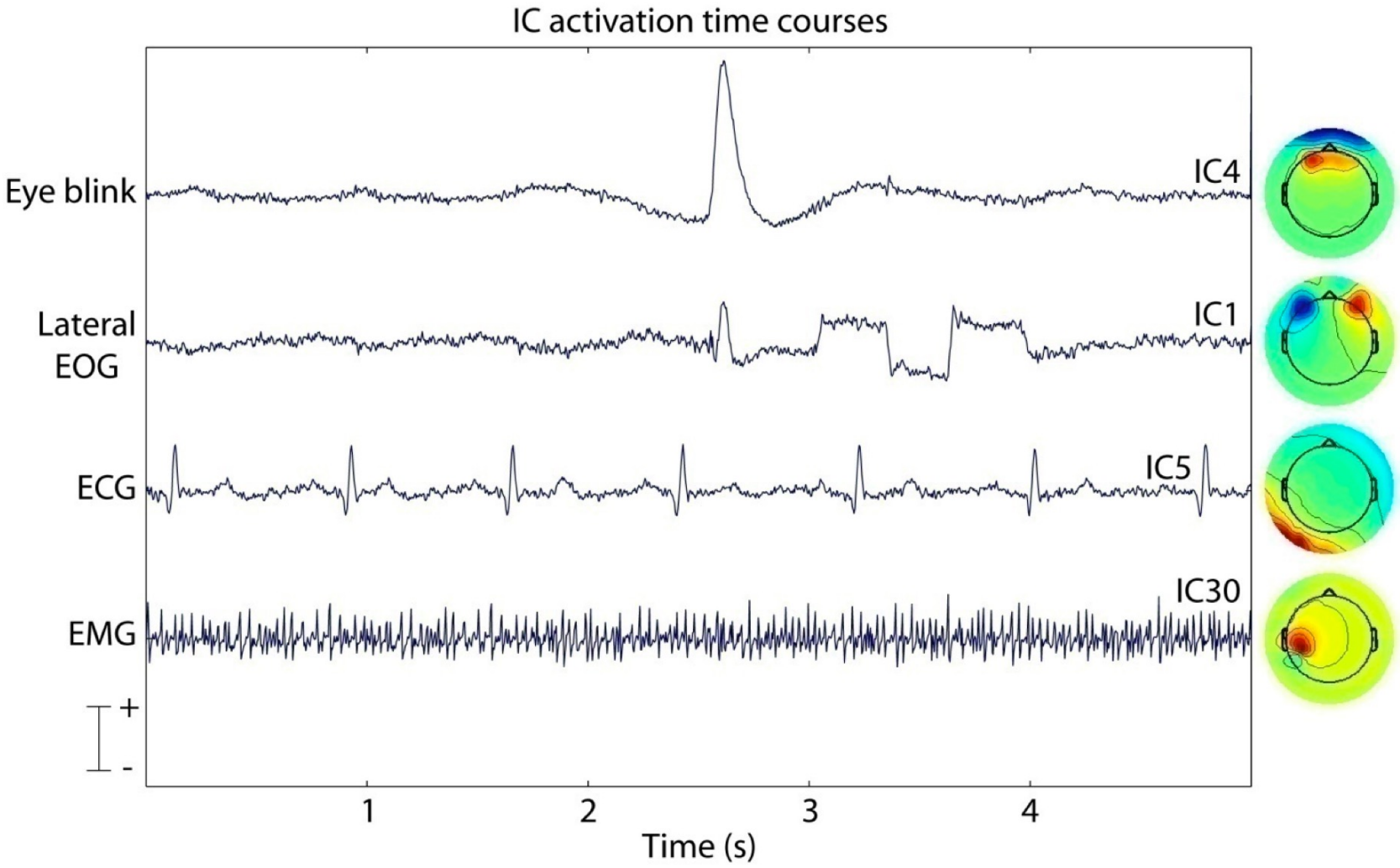
- ***What* are the effective sources? (identification)**

And it greatly helps answer the second question:

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

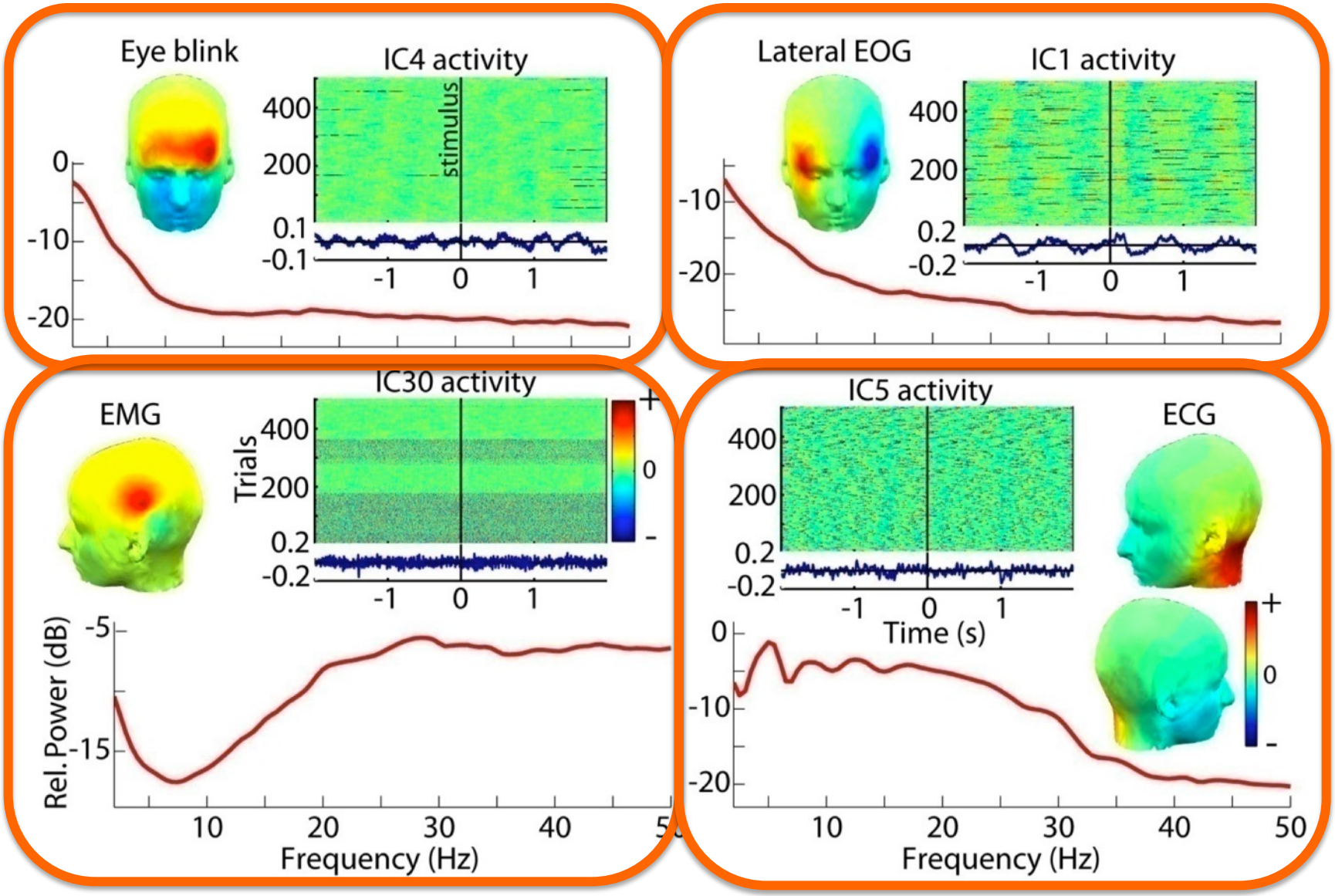


ICA separates *non-brain* effective source processes



J. Onton & S. Makeig 2006

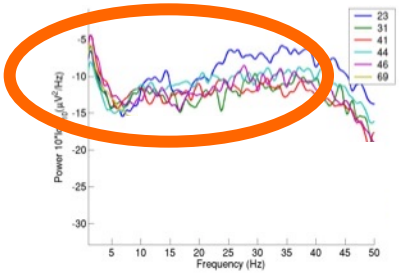
ICA finds non-brain independent component (IC) processes …

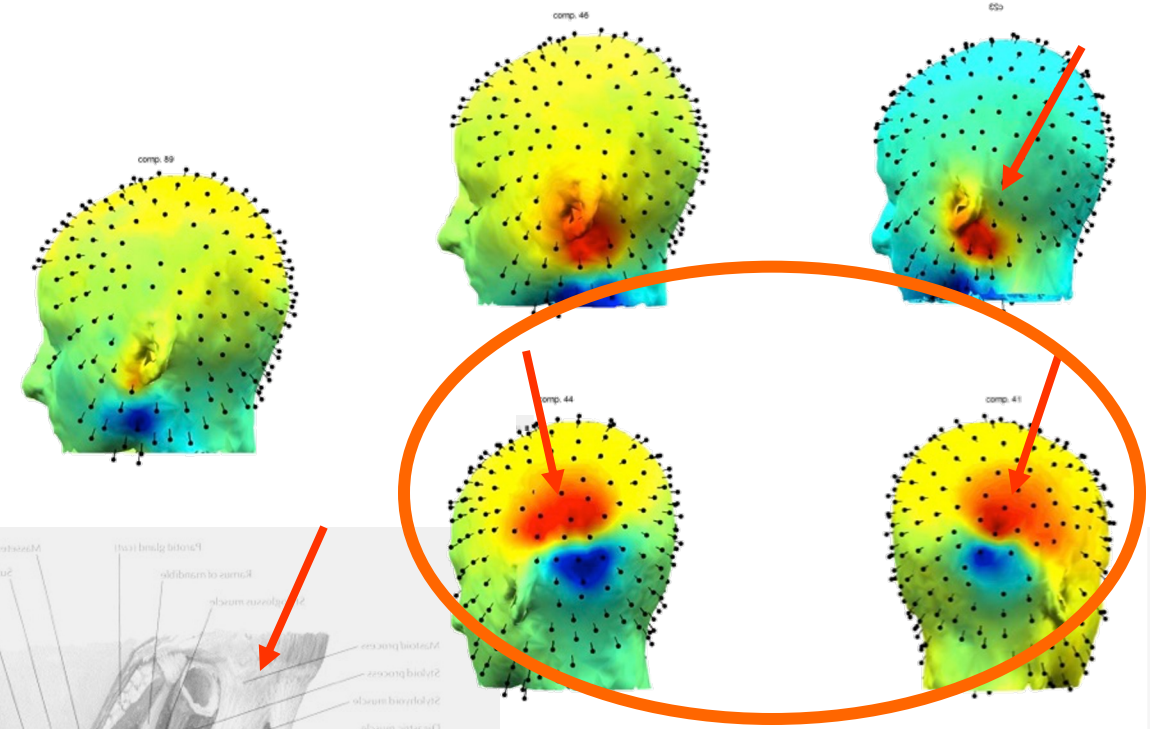


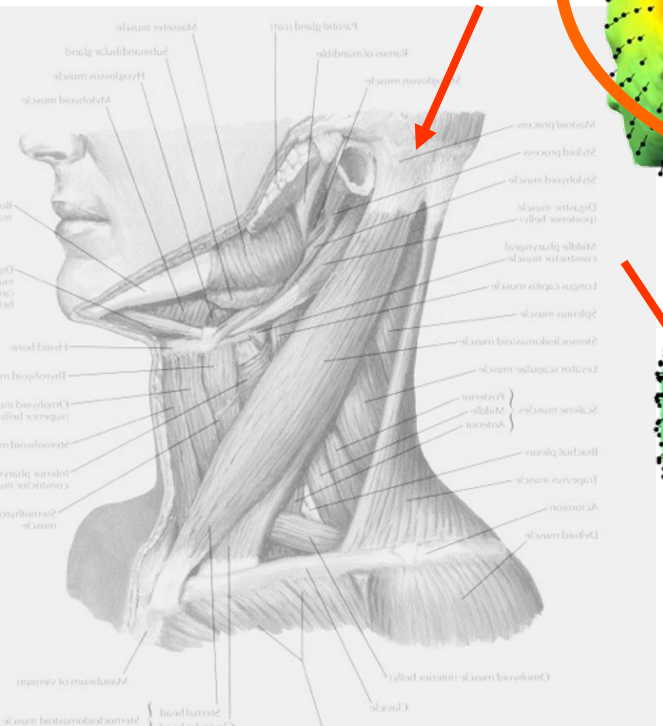
… separates them from the remainder of the data …

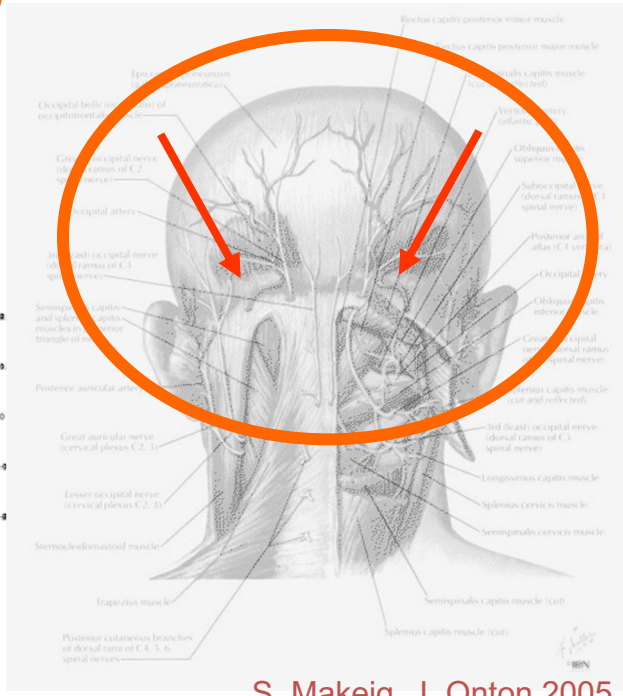
J. Onton & S. Makeig 2006

… including IC EMG sources



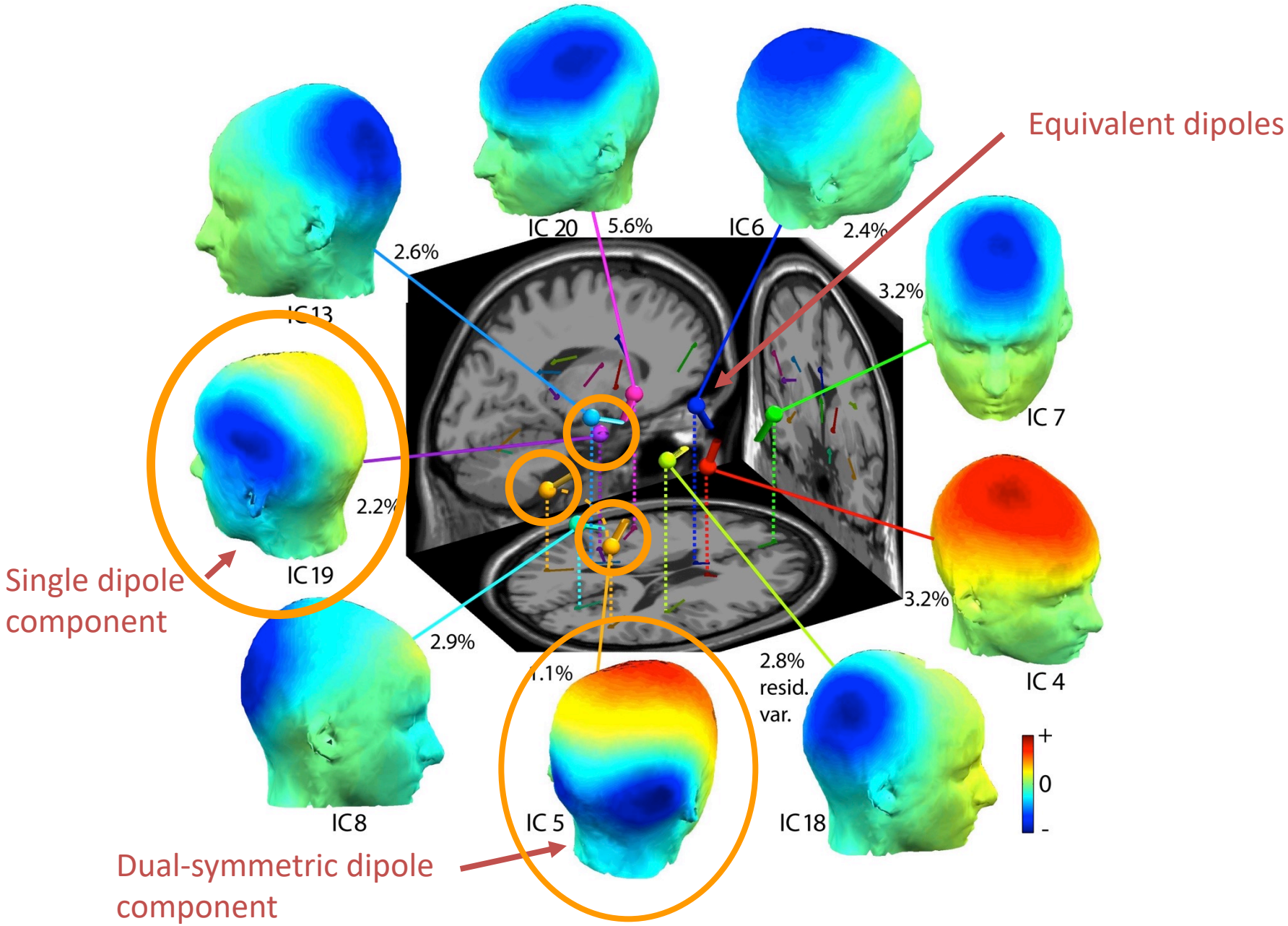






S. Makeig, J. Onton 2005

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



Julie Onton & S. Makeig (2006)

ICLabel: A crowd-sourced AI independent component classifier

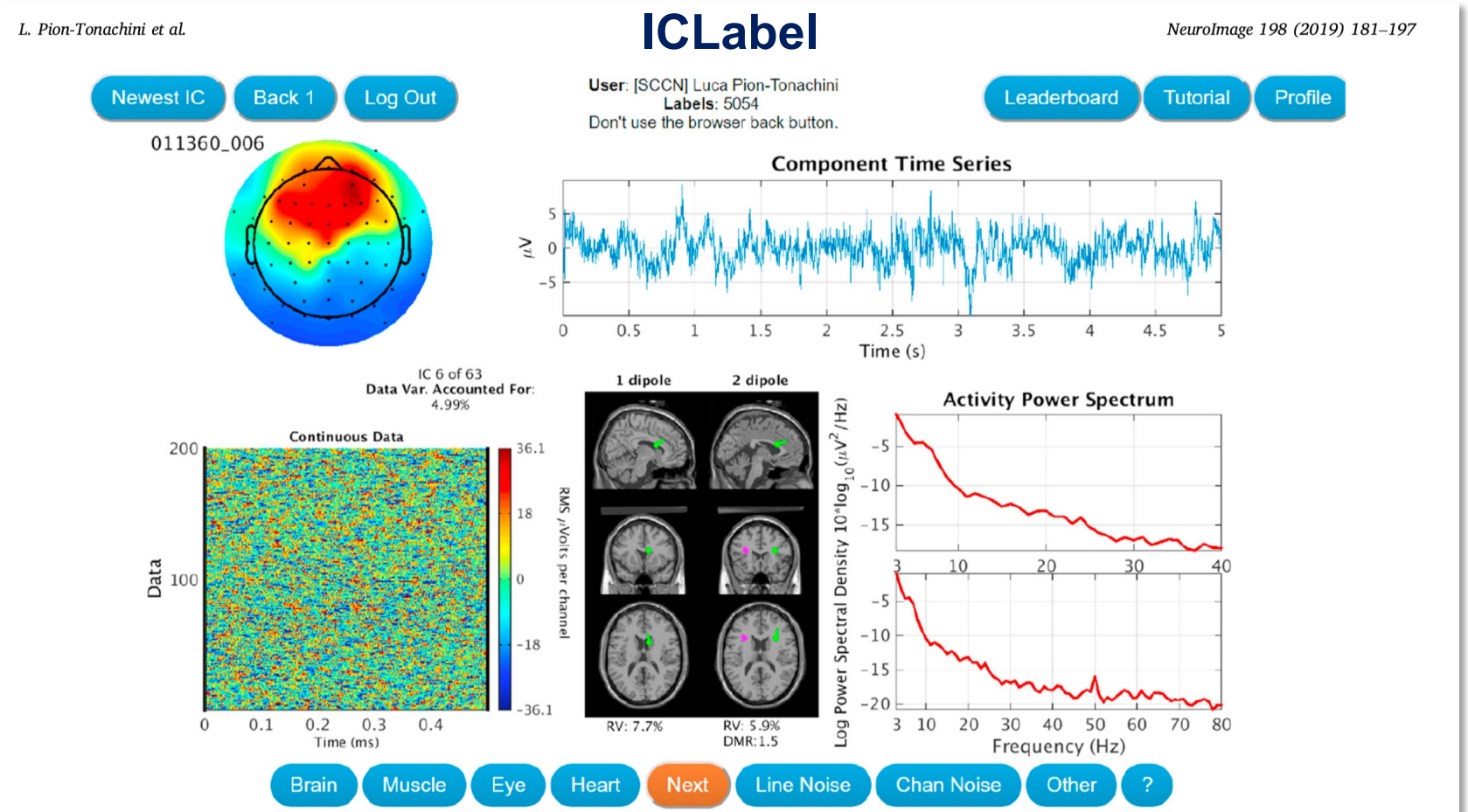
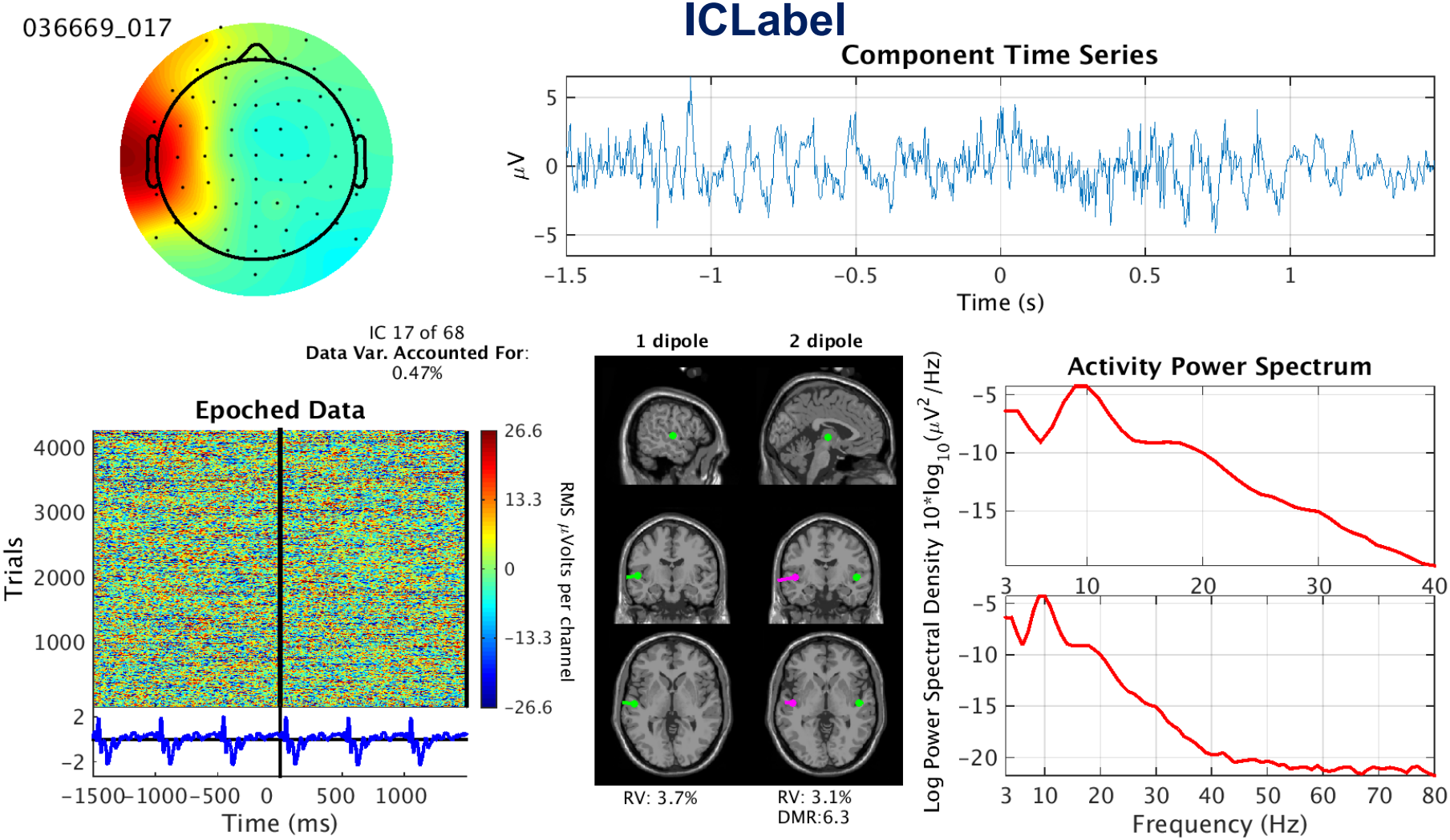


Fig. 1. An IC labeling example from the ICLabel website (https://iclabel.ucsd.edu/tutorial), which also gives a detailed description of the features shown above. Label contributors are shown the illustrated IC measures and must decide which IC category or categories best apply. They mark their decision 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.

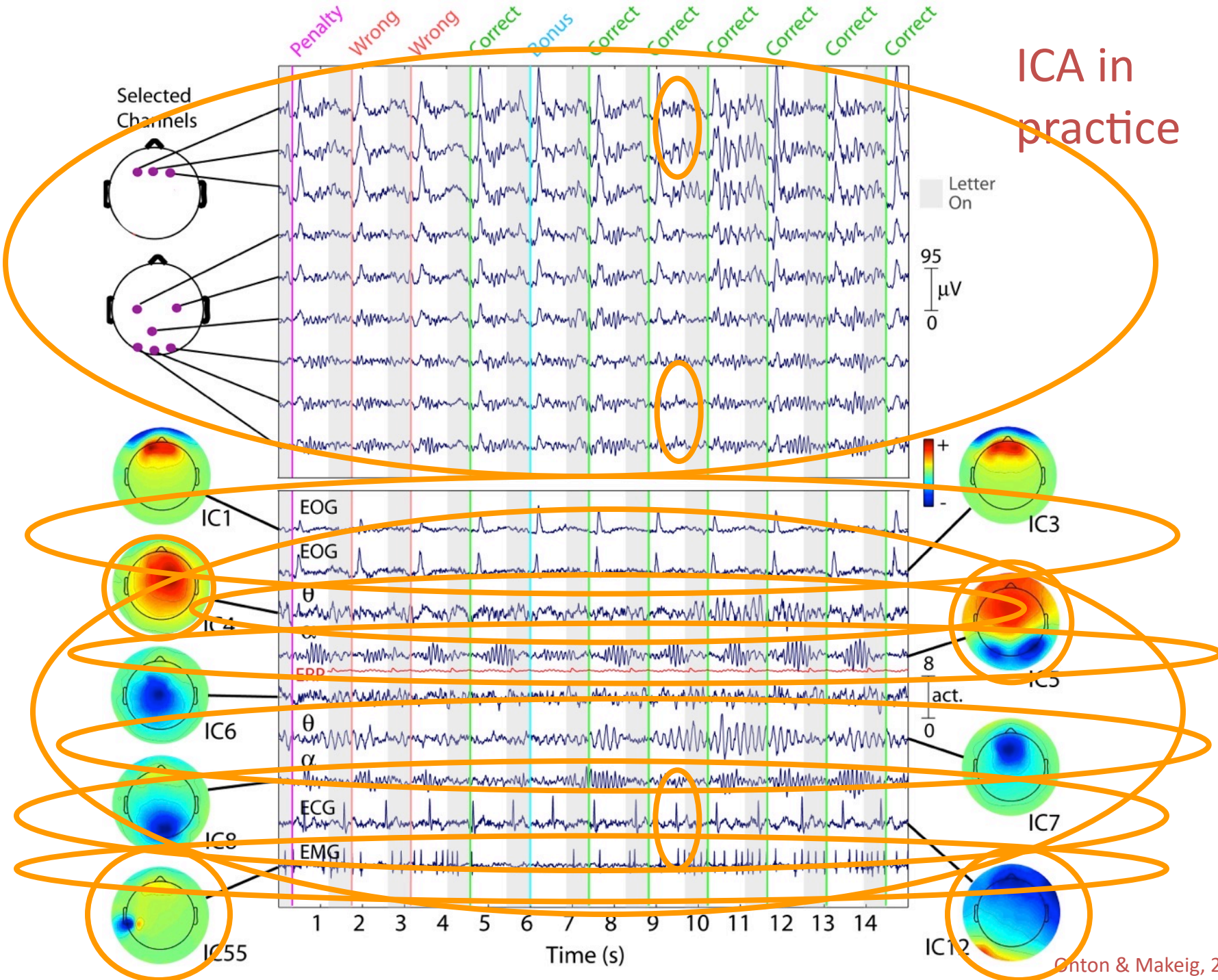
labeling.ucsd.edu/tutorial

ICLabel: A crowd-sourced AI independent component classifier



labeling.ucsd.edu/tutorial

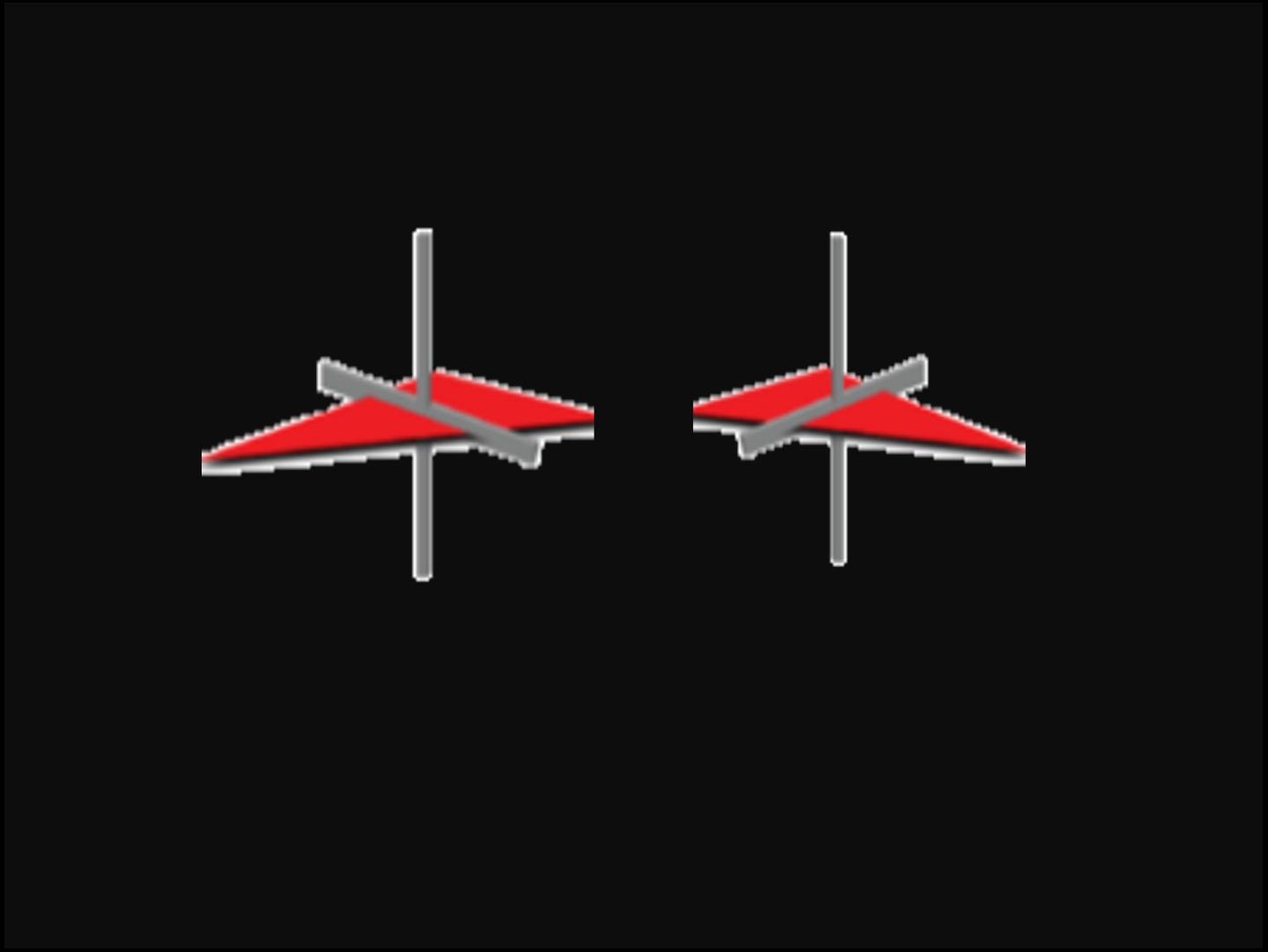
Luca Pion-Tonachini, 2019



Onton & Makeig, 2006


Klaus Gramann
3-D Tunnel Task

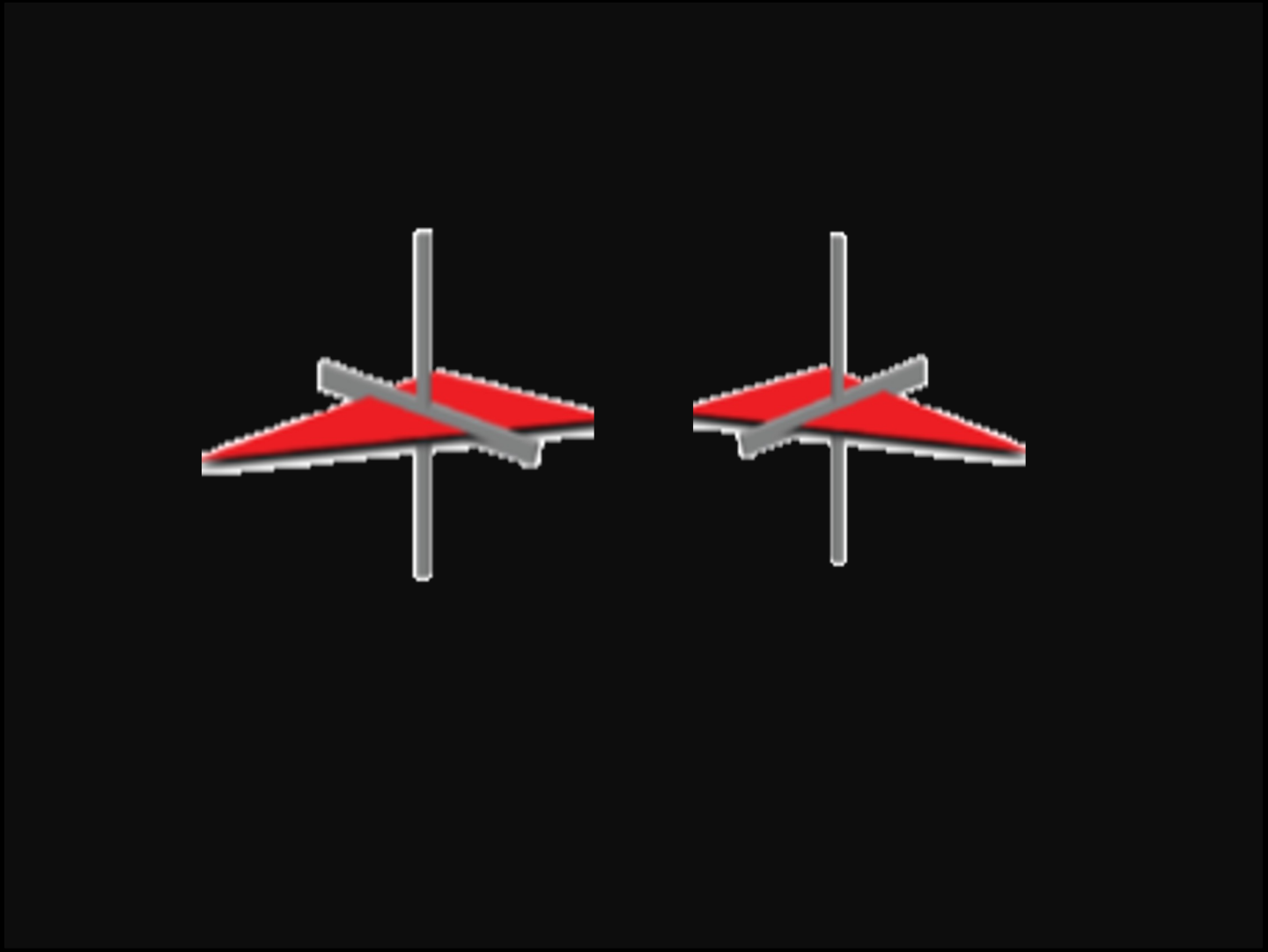
A Passive Spatial Navigation Paradigm



Klaus Gramann et al., 2010

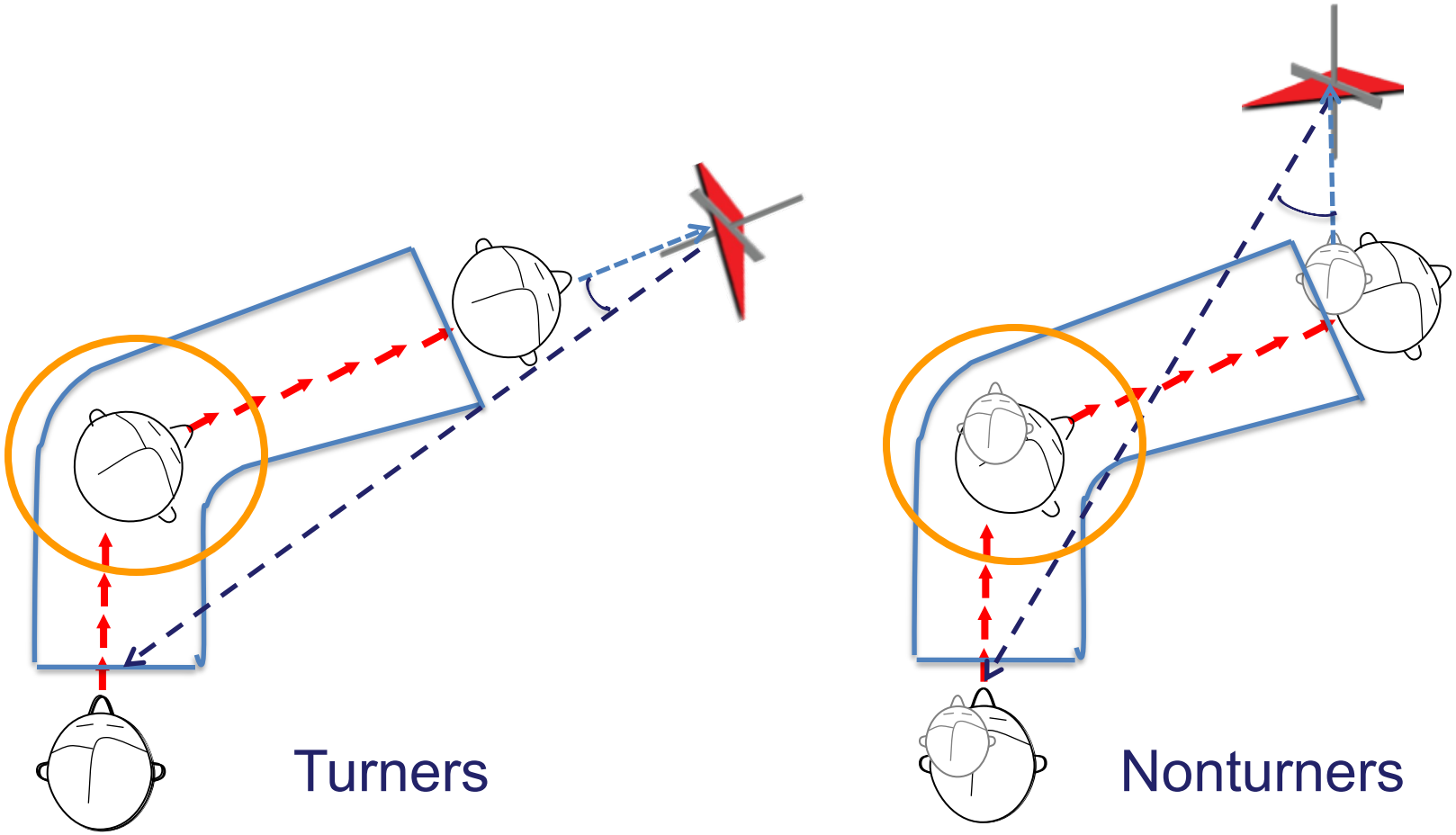
Klaus Gramann et al., 2010

A Passive Spatial Navigation Paradigm



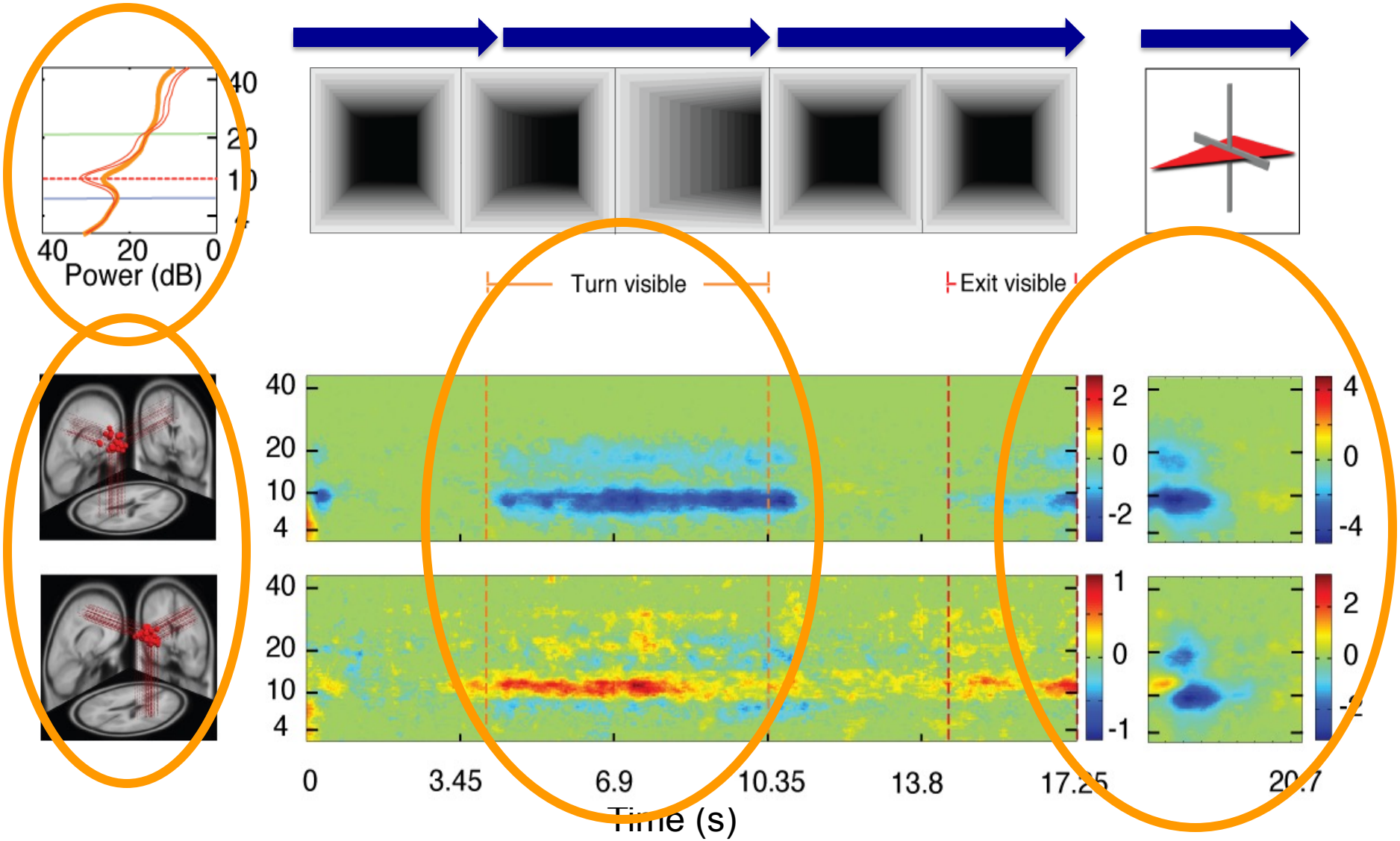
Klaus Gramann et al., 2010

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



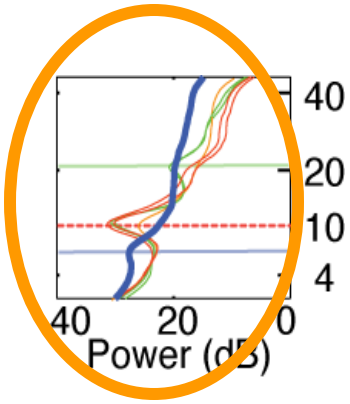
Klaus Gramann & S. Makeig, 2010

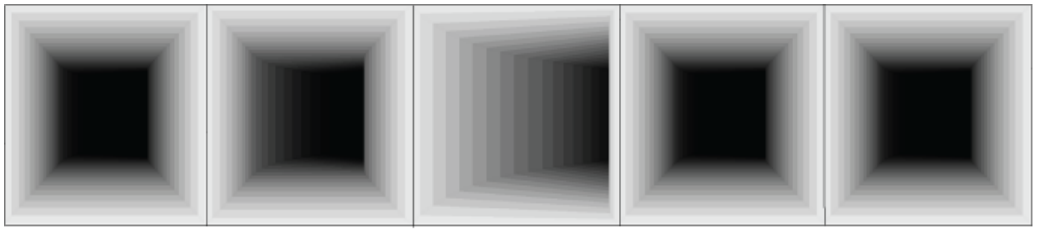
Two parietal component clusters

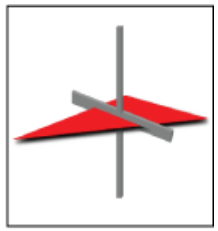


Klaus Gramann et al., 2010

Medial prefrontal component cluster

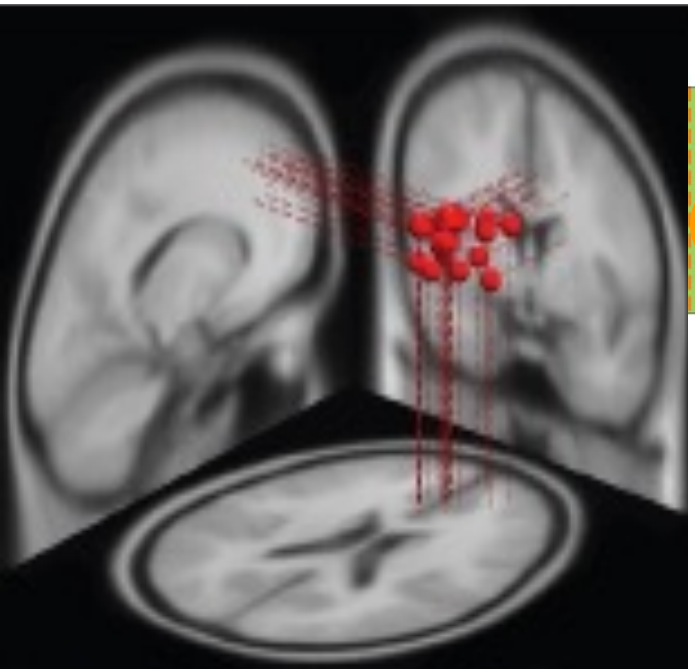


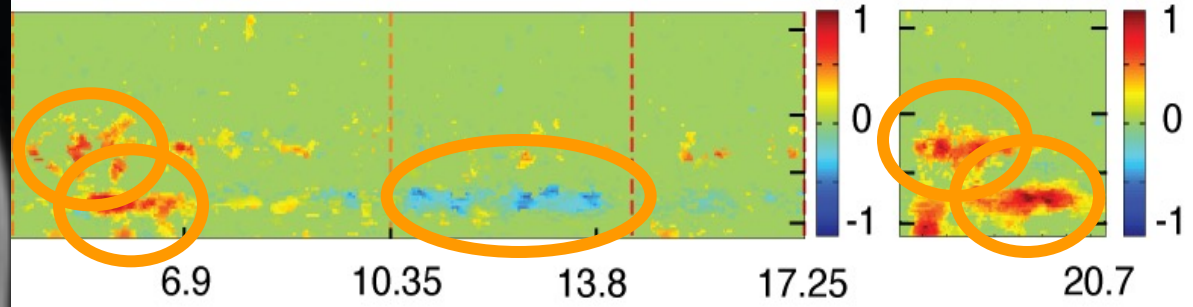




Turn visible

Exit visible

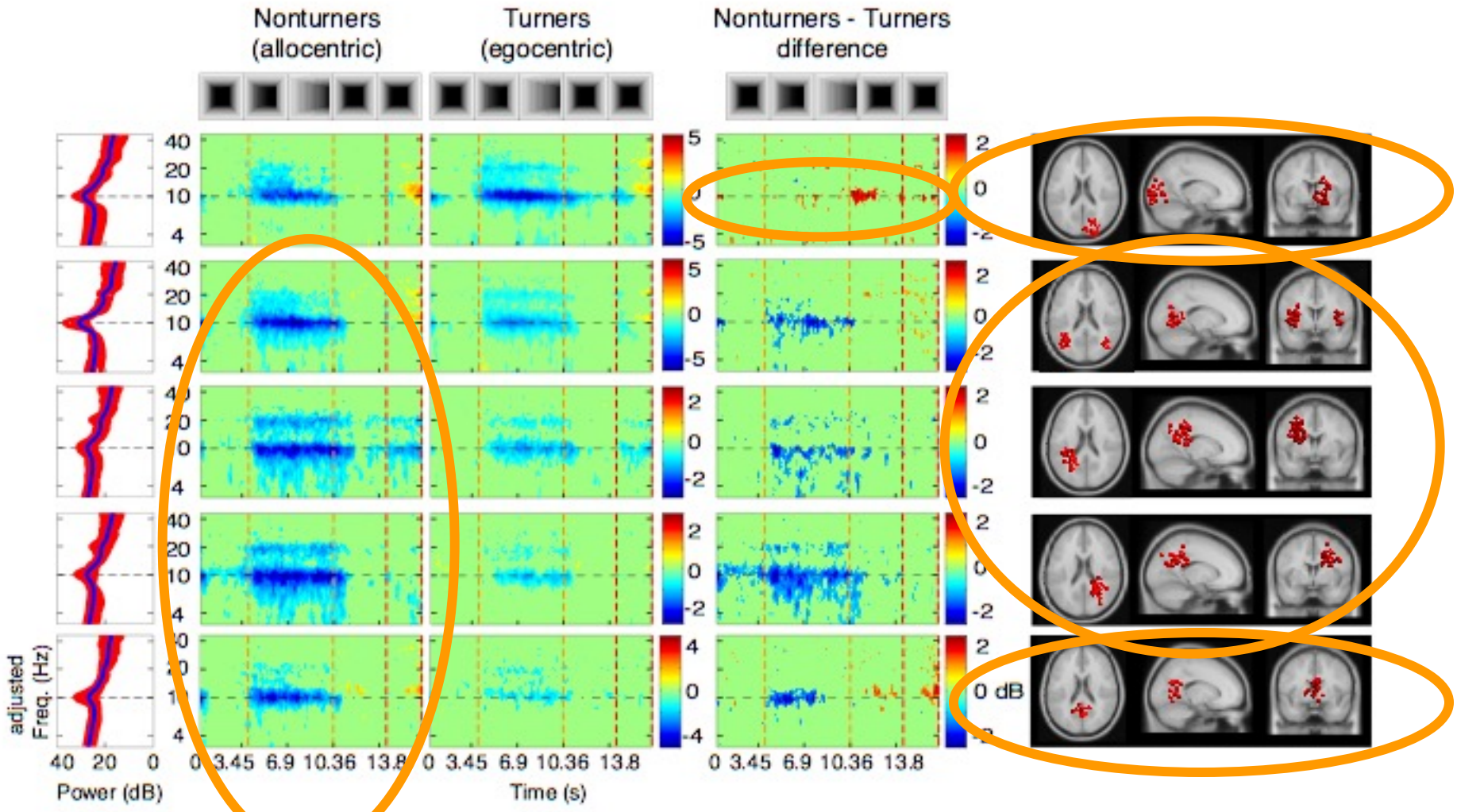




Time (s)

Klaus Gramann et al., 2010

Clusters distinguishing Turners & Nonturners



Klaus Gramann et al., 2010

Swartz Center for Computational Neuroscience

The Beginning

EEG brain imaging

etc. . . .