Event-Related Brain Dynamics I

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26th EEGLAB Workshop

Be'er Sheeva, Israel

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Human Functional Brain Imaging

Some human brain imaging milestones

1926 ~1st human EEG recordings

EEG era

1938 1st EEG spectral analysis

1962 ~1st computer ERP averaging (CAT)

ERP era

1979 1st event-related desynchronization

1993 1st fMRI BOLD recordings

fMRI era

1993 1st broadband ERSP

1995 1st multisource EEG filtering by ICA

2009 ~1st commercial dry electrode EEG toys

fEEG / BMI / MoBI era …

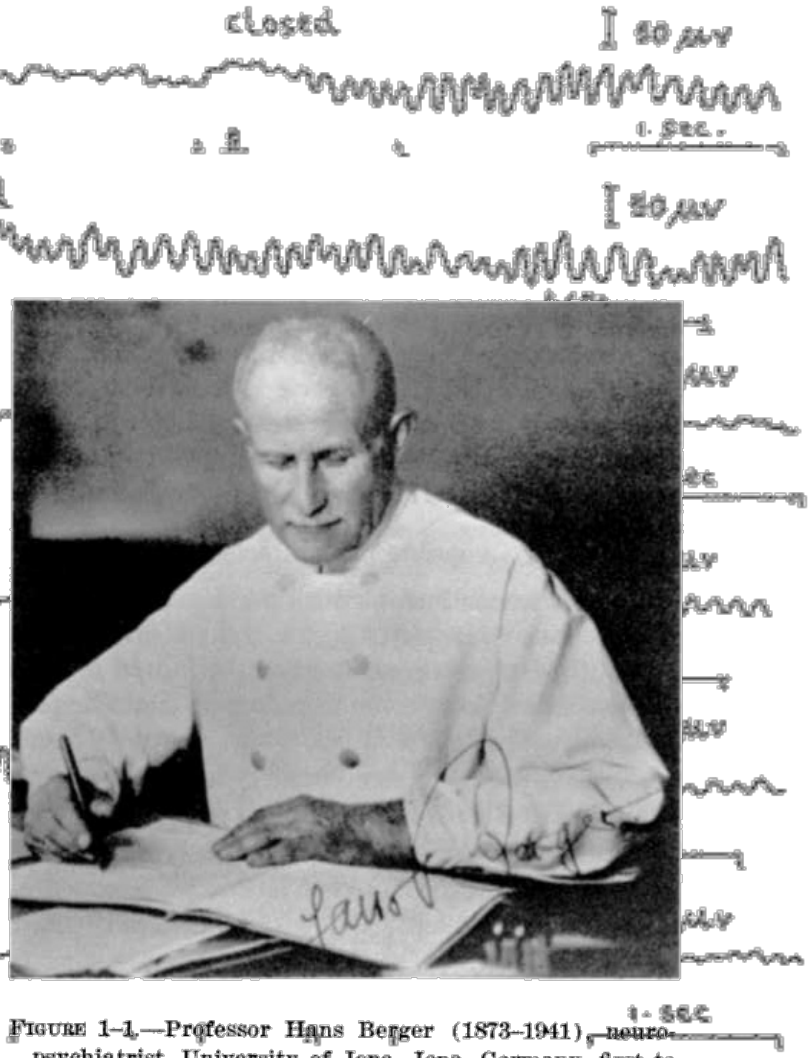
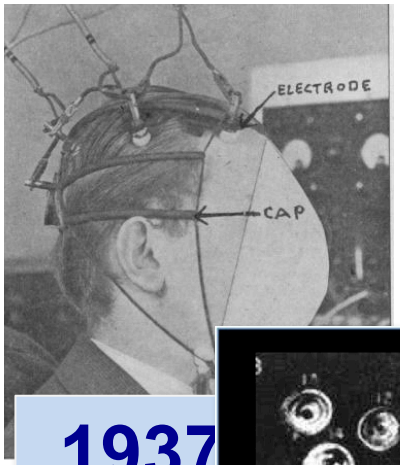


FIGURE 1–1.—Professor Hans Berger (1873–1941), neuropsychiatrist, University of Jena, Jena, Germany, first to discover and describe in 1929 a unique kind of electrical activity recorded from the brain of man, which he named the electroencephalogram (Elektrenkephalogramm).

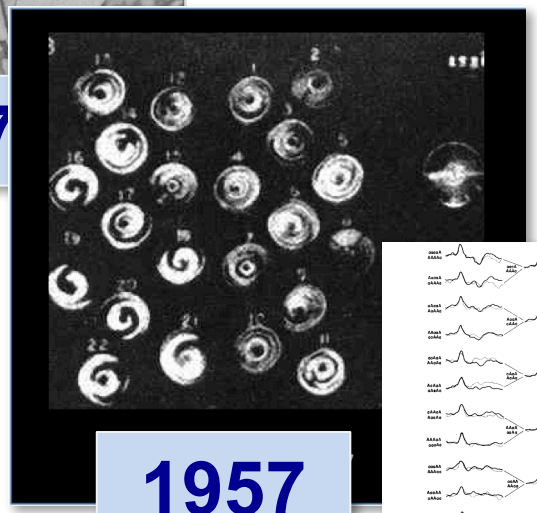
FIGURE 1–2.—Sample of the first EEG tracing taken at the Bradley Hospital, E. Providence, Rhode Island, by H. Jasper and L. Carmichael. Subject: Carl Pfaffmann. Date: July 9, 1934. Record, which shows prominent alpha rhythm of about 11.5 per second, was made with a Westinghouse, galvanometer-type, mirror oscillograph. Time line above: 25 Hz.

S. Makeig 2010

Development of EEG brain Imaging …

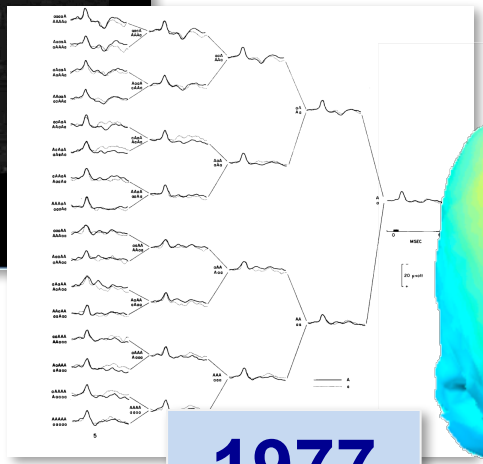


1937



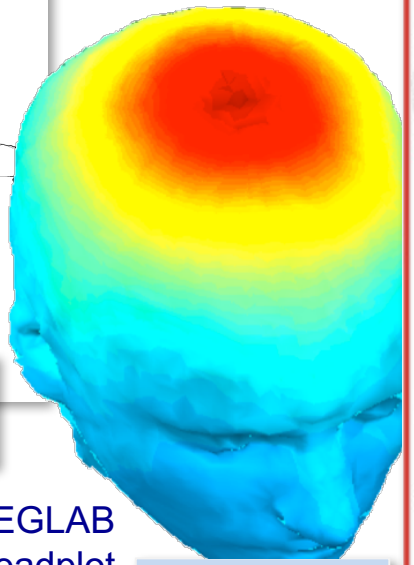
1957

Toposcope
Grey Walter



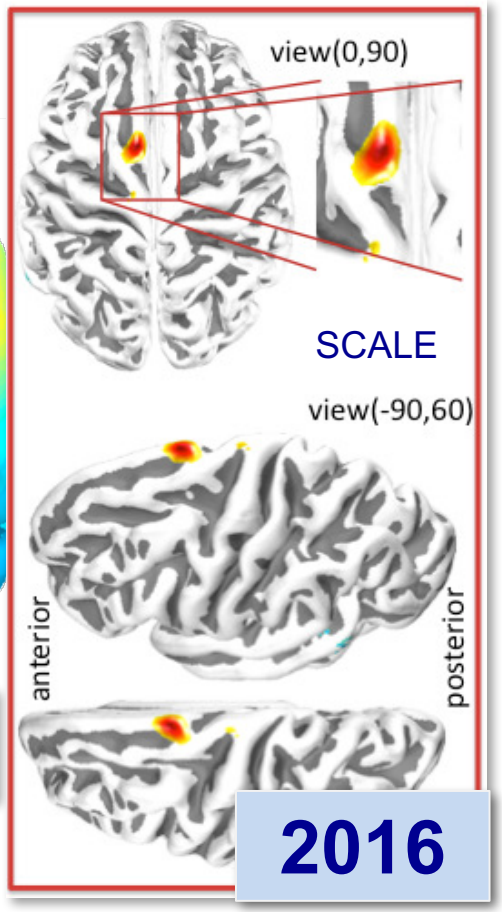
Oddball ERPs
K. Squires et al.

1977



EEGLAB
headplot

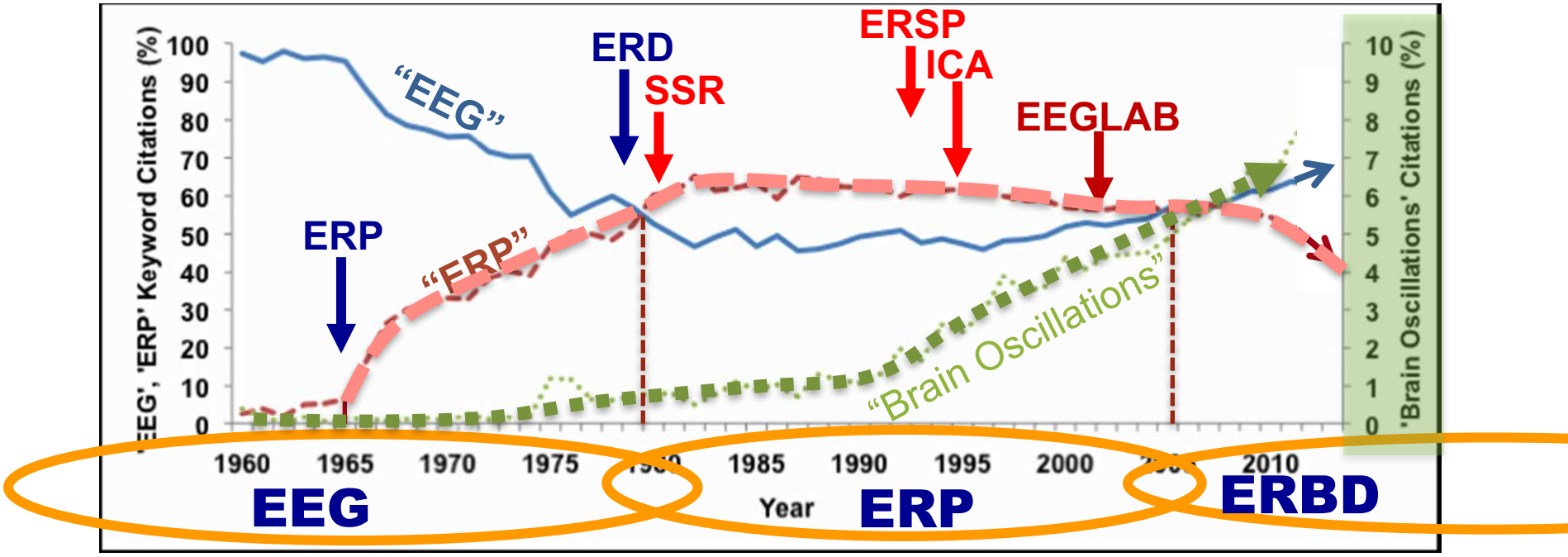
1997



2016

Z. Akalin Acar et al.

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

Functional Brain Imaging

Hemodynamic imaging

= imaging local brain

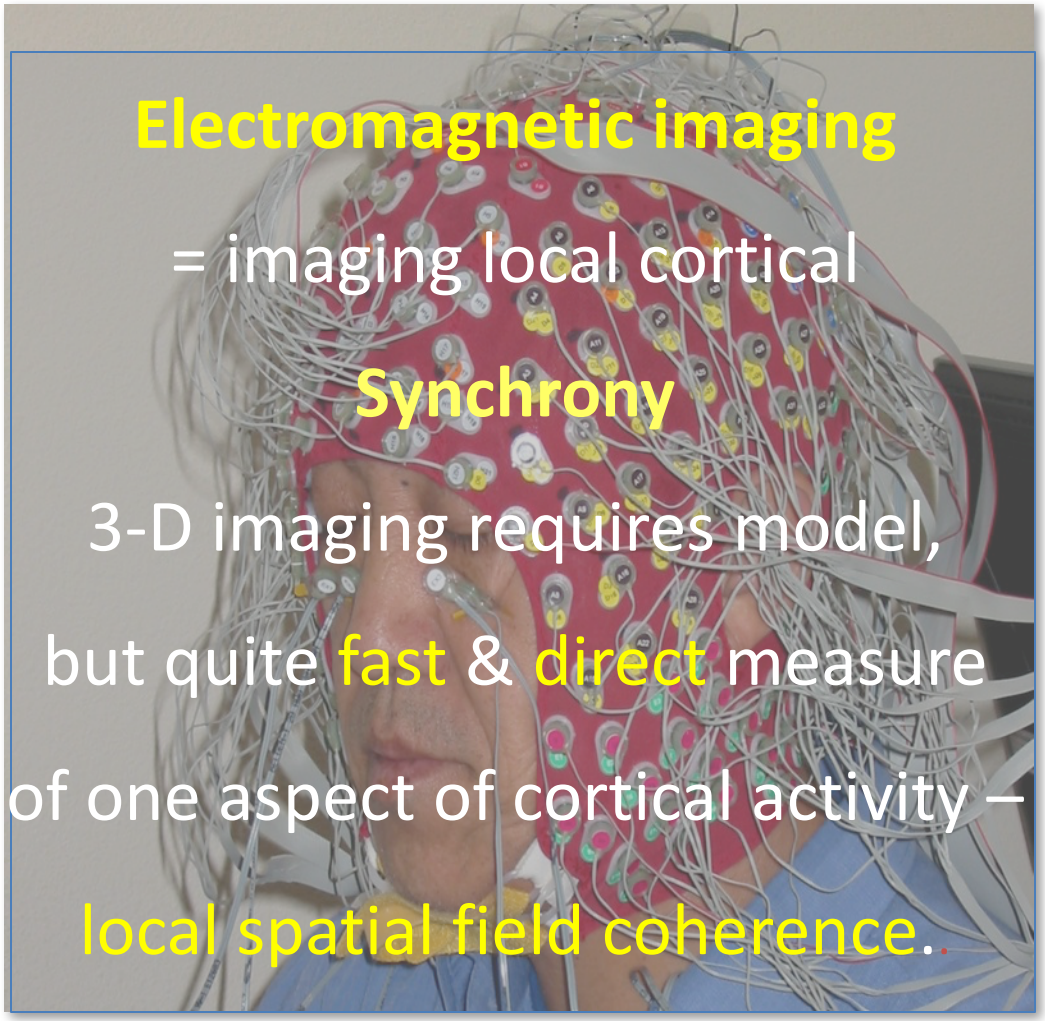
Energy

Direct 3-D inverse model,

but quite slow & indirect

as well as expensive,

heavy, non-portable.



Electromagnetic imaging

= imaging local cortical

Synchrony

3-D imaging requires model,

but quite fast & direct measure

of one aspect of cortical activity –

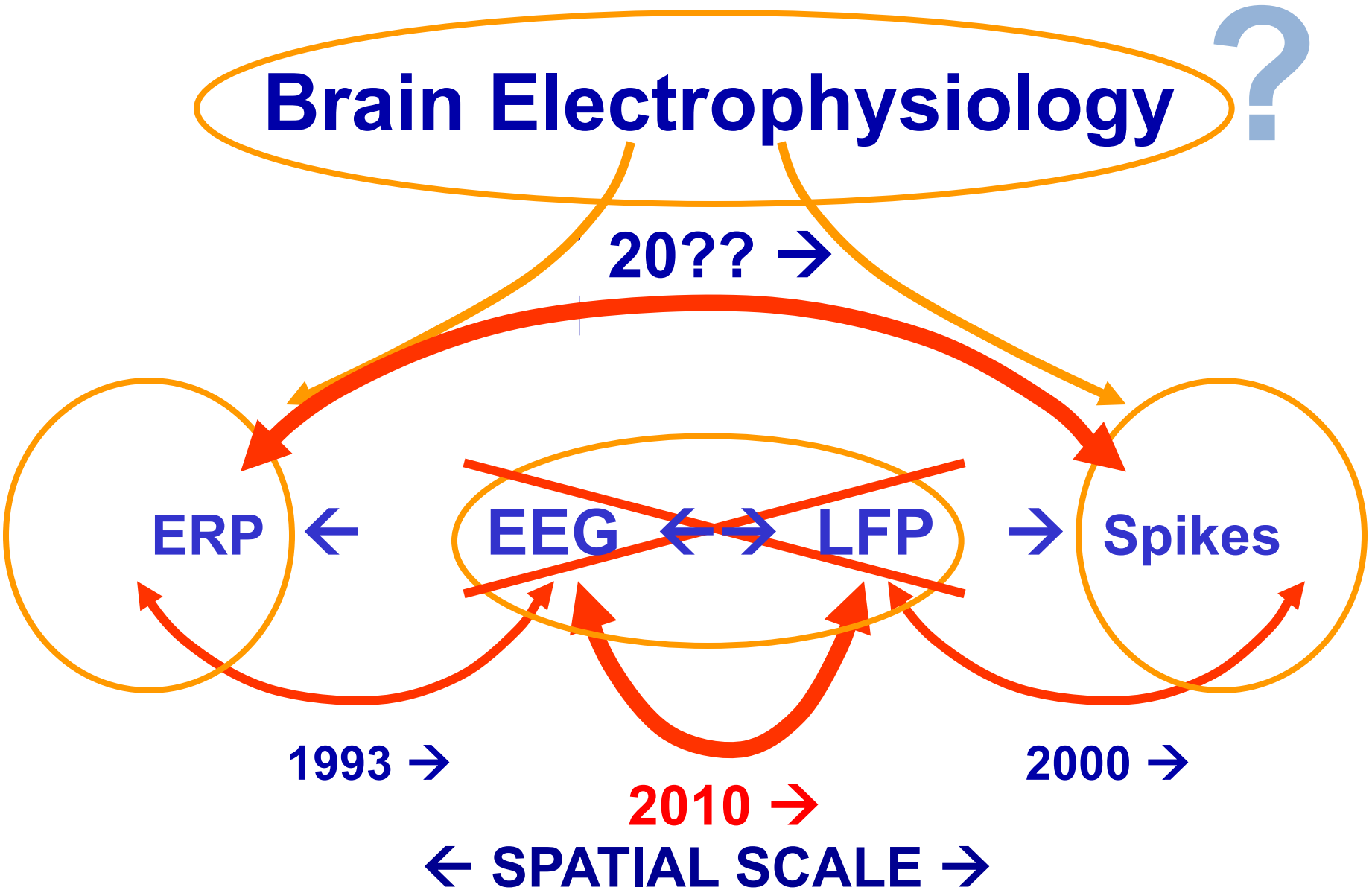
local spatial field coherence.

Advantages of Functional Brain Imaging using EEG

- EEG is noninvasive → little ethical concern
- EEG has fine time resolution
- EEG can be tolerated by most subjects
- EEG is lightweight / mobile / wearable
- EEG is / can be inexpensive → scalable

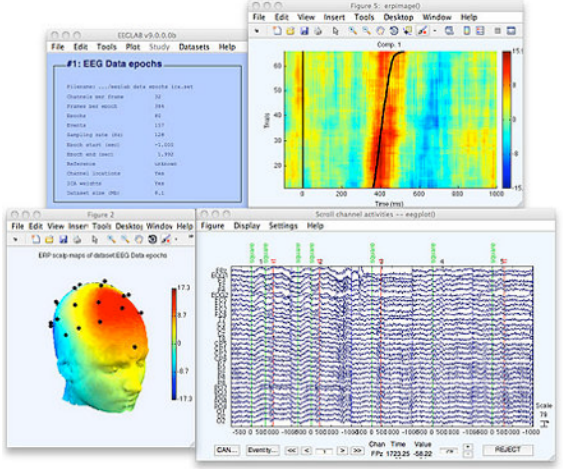
Disadvantages of Functional Brain Imaging using EEG

- EEG channels each mix cortical field dynamics.
- EEG channel signals also sum potentials from non-brain sources.
- EEG cannot tolerate head scratching (etc.) and may not be convenient to wear.
- Localizing brain EEG sources requires an accurate electrical head model.



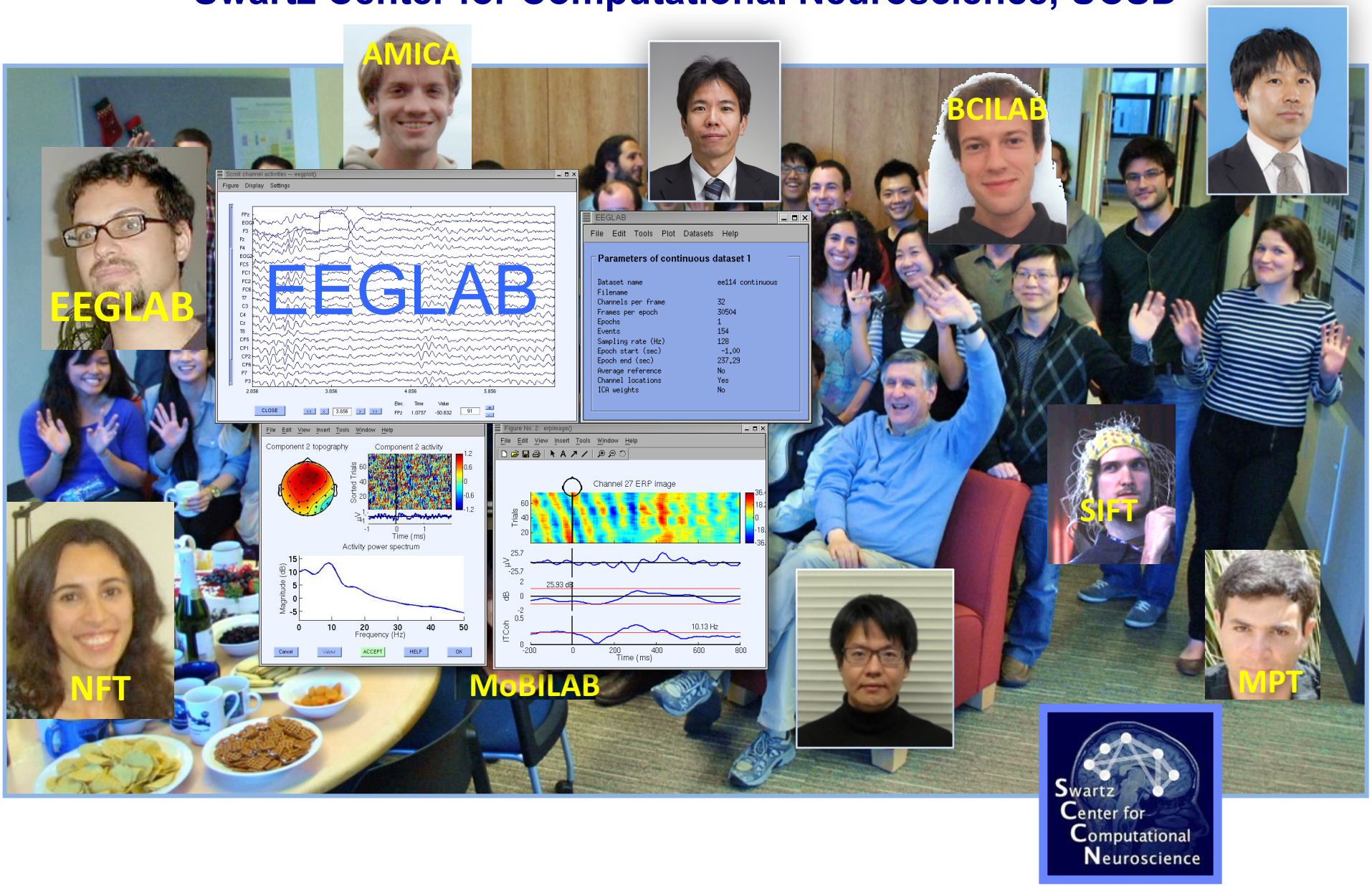
S. Makeig, *TINS* 2002

EEGLAB History

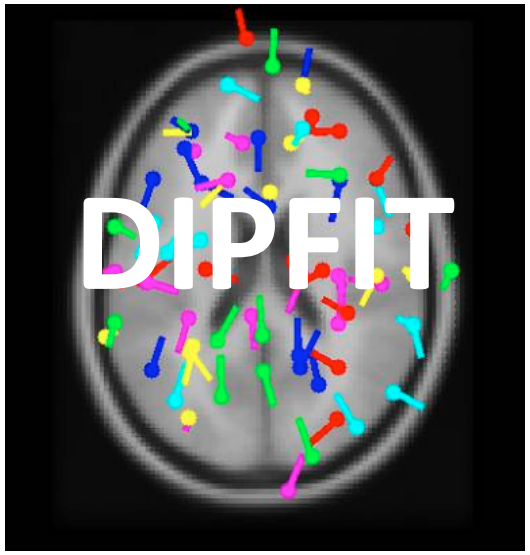


- 1993 – ERSP (Makeig)
- 1995 – Infomax ICA for EEG (Makeig, Bell, Jung, Sejnowski)
- **1997 - EEG/ICA Toolbox (cnl.salk.edu), ITC & ERC**
- 1999 - ERP-image plotting (Jung & Makeig)
- 2000 – **EEGLAB GUI design (Delorme)**
- **2002 – 1st EEGLAB (sccn.ucsd.edu)**
- **2004 - 1st EEGLAB support from U.S. 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 …**

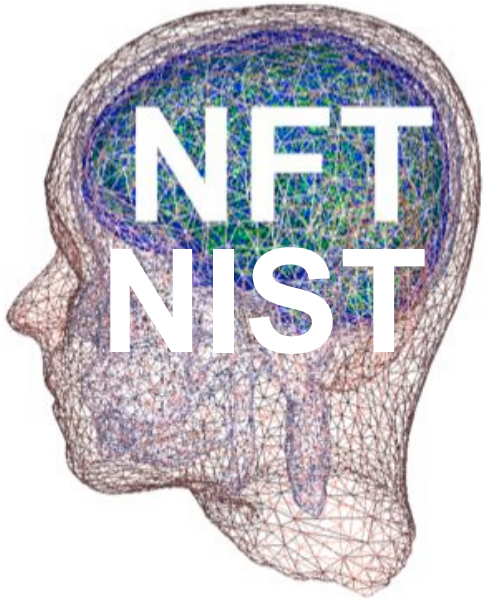
Swartz Center for Computational Neuroscience, UCSD

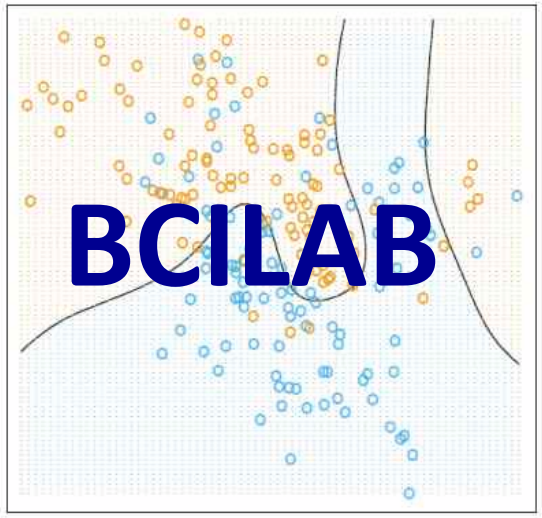


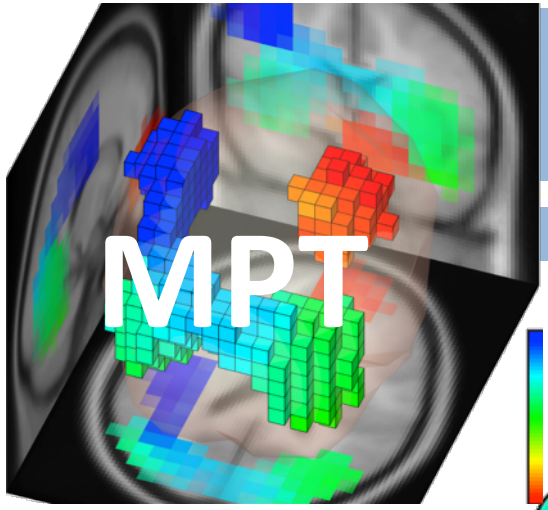
10th Anniversary SCCN Impromptu celebration 1/2/12

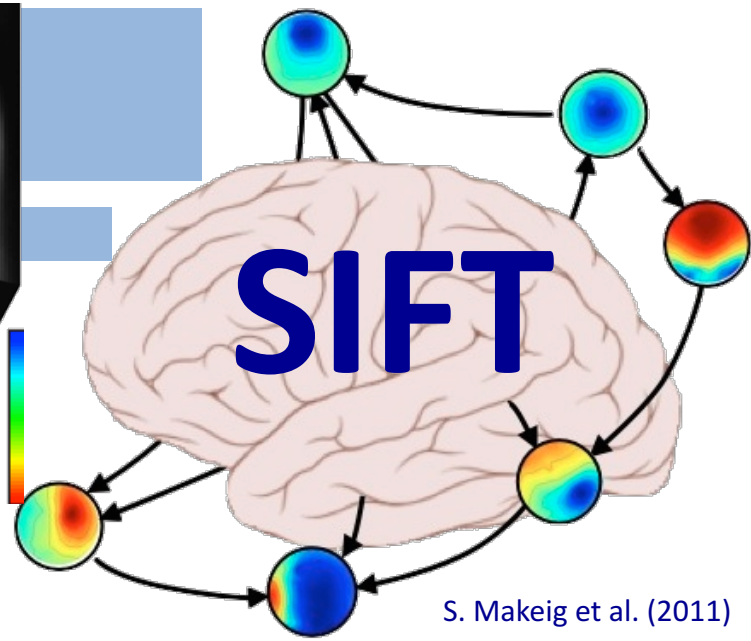


EEGLAB Plug-In Extensions









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. Cullen	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

List of data processing extensions

Plug-in name	Version	Short plug-in description	Link	Contact	Comments
rERP	0.4	Estimate overlapping ERPs using multiple regression	Download	M. Burns	User comments
LIMO	1.5	LInear MOdelling of EEG data	Download	C. Pernet	User comments
corrmap	2.02	Cluster ICA components using correlation of scalp maps	Download	S. Debener	User comments
bioelectromag	1.01	Uses Bioelectromagnetism toolbox for ERP peak detection	Download	D. Weber	User comments
VisEd	1.05	Add/Edit dataset events	Download	J. Desjardins	User comments
loreta	1.10	Export and import data to and from LORETA software	Download	A. Delorme	User comments
iirfilt	1.02	Non linear filtering using IIR filter	Download	M. Pozdin	User comments
std_envtopo	2.39	Plot STUDY ICA cluster contribution to ERP	Download	M. Miyakoshi	User comments
std_selectICsByCluster	0.10	Forward-project clustered ICs to channels (beta)	Download	M. Miyakoshi	User comments
std_dipoleDensity	0.23	Plot STUDY ICA cluster dipole density (beta)	Download	M. Miyakoshi	User comments
std_ErpCalc	0.11	Test and visualize simple effects on ERP (beta)	Download	M. Miyakoshi	User comments
pvaftopo	0.10	Plot topography of percent variance accounted for (beta)	Download	M. Miyakoshi	User comments
trimOutlier	0.16	Trim outlier channels and datapoints interactively (beta)	Download	M. Miyakoshi	User comments
clean_rawdata	0.31	Cleans continuous data using Artifact Subspace Reconstruction	Download	Miyakoshi and Kothe	User comments
ARfitStudio	0.10	Cleans spiky artifacts using AFfit (beta)	Download	Miyakoshi and Mullen	User comments
Mutual_Info_Clustering	1.00	Group single dataset ICA components by Mutual Information	Download	N. Bigdely	User comments
mass_univ	130502	Mass Univariate ERP Toolbox	Download	D. Groppe	User comments
REGICA	1.00	ICA regression based EOG removal	Download	M. Klados	User comments
MARA	1.1	Multiple Artifact Rejection Algorithm	Download	I. Winkler	User comments
firfilt	1.6.1	Routines for designing linear filters	Download	A. Widmann	User comments
PACT	0.17	Computes phase-amplitude coupling for continuous data	Download	M. Miyakoshi	User comments
fMRIb	2.00	Remove fMRI artifacts from EEG	Download	J. Dien & R. Niazy	User comments
SIFT	1.33	Analysis and visualization of multivariate connectivity	Download	T. Mullen	User comments
AAR	131130	ICA-based Automatic Artifact Removal	Download	G. Gomez-Herrero	User comments
Adjust	1.1	Automatic Detector - Joint Use of Spatial and Temporal features	Download	Adjust Support	User comments
Cleanline	1.02	Removes sinusoidal artifacts (line noise)	Download	T. Mullen	User comments
Fieldtrip-lite	Daily	Adds source localization and statistics tools to EEGLAB	Download	R. Oostenveld	User comments
EYE-EEG	0.41	Open source MATLAB tool for simultaneous eye tracking & EEG	Download	O. Dimigen	User comments


Who
am I?

Embodied Agency

Brain processes

have evolved and function

to optimize the ***outcomes***

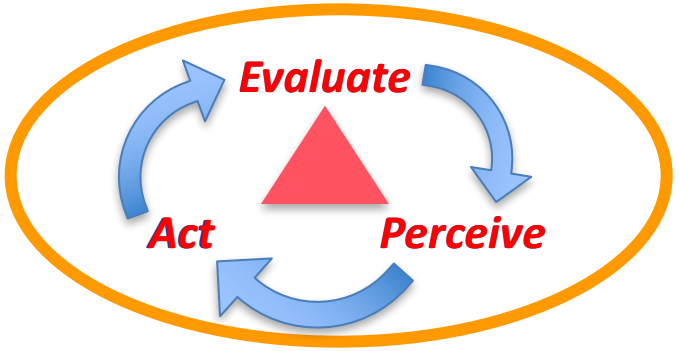
of the ***behavior***

the brain organizes

in response to

perceived challenges

and opportunities.



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

S Makeig 2010

Embodied Agency

Brain processes

have evolved and function

to optimize the outcomes

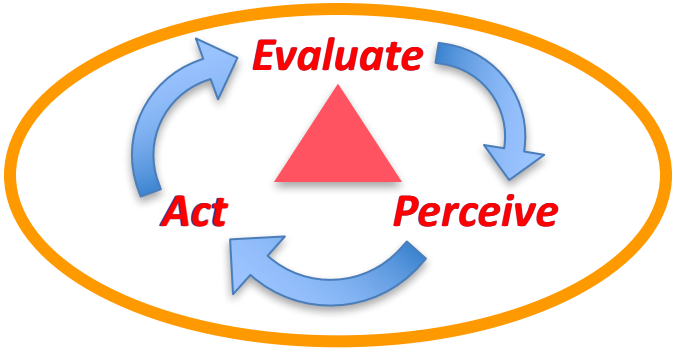
*of the **willed** behavior*

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 (recall, believe)

Feeling - I feel (experience as feeling)

Willing - I act (intend)

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

Avatar Meher Baba
(*Discourses*, 6th Ed., II, p. 141)

EEG & Cognitive Neuroscience

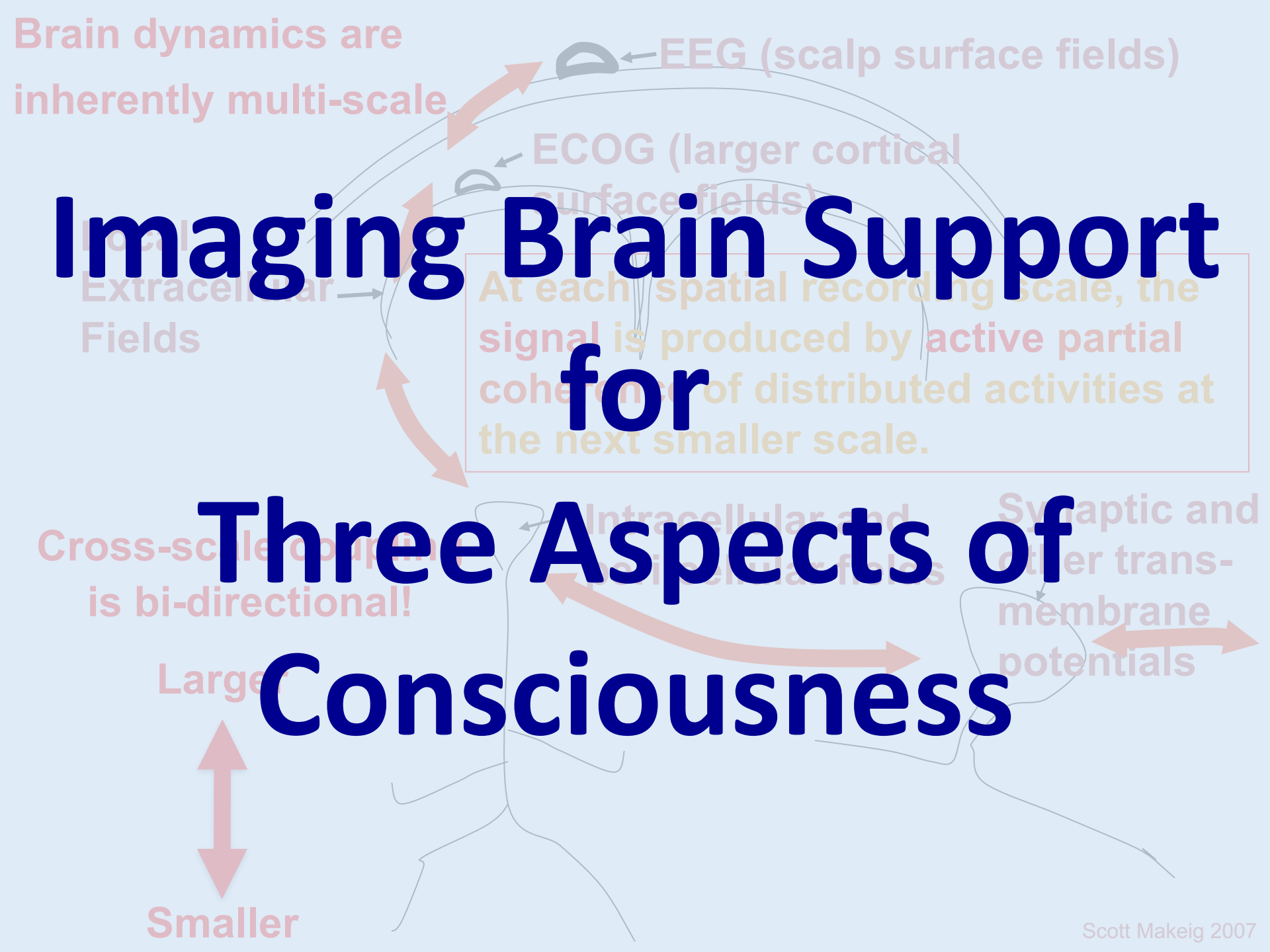
EEG can be used to learn

how the brain and nervous system

supports and sustains human consciousness

In all its aspects --

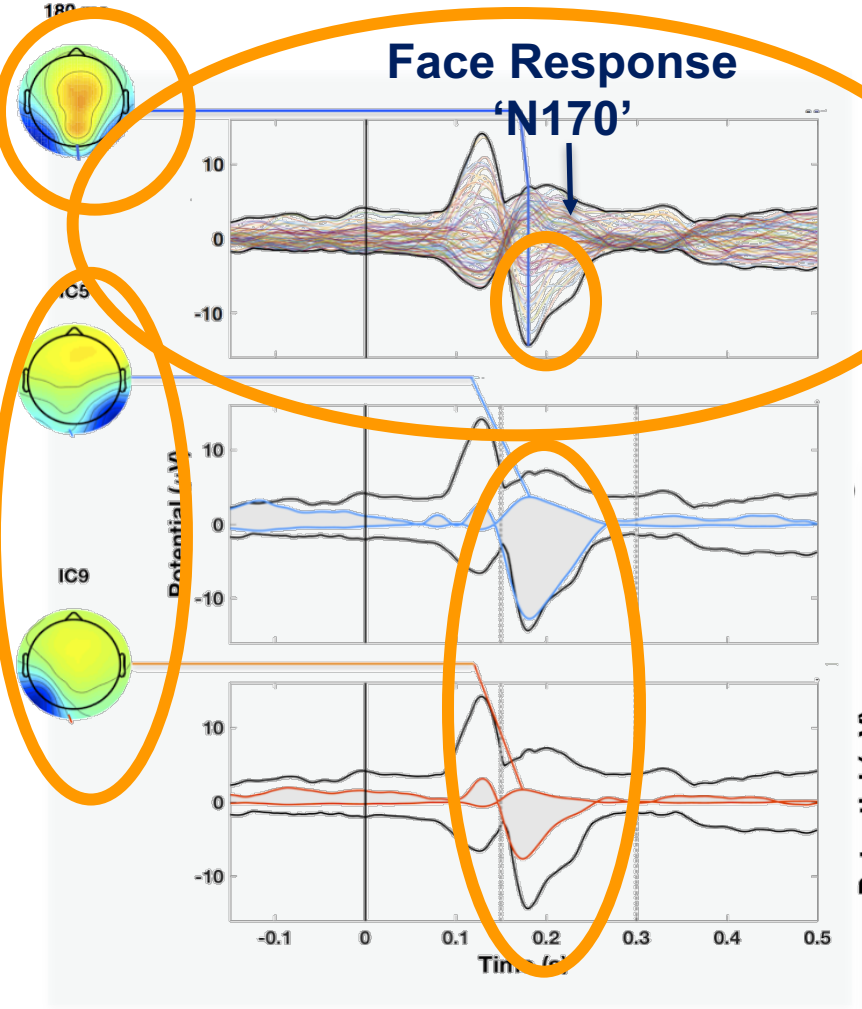
S. Makeig (2017)

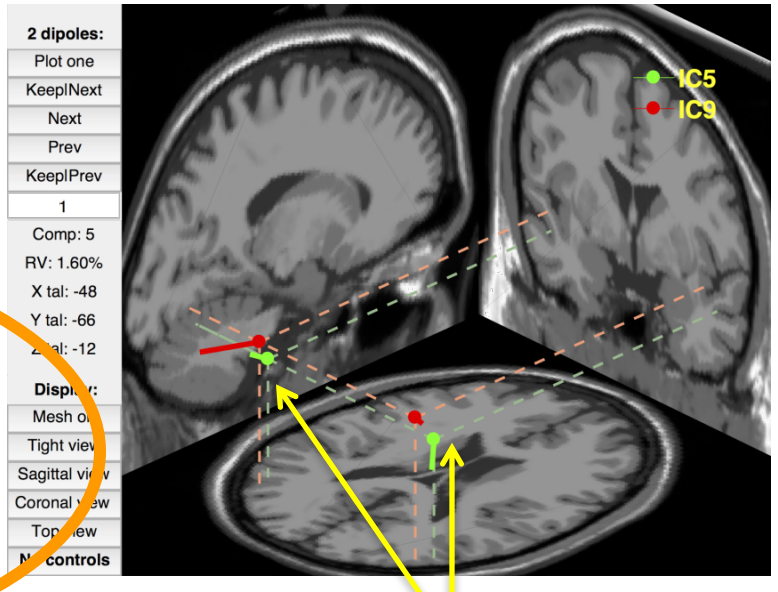


Imaging Brain Support for Three Aspects of Consciousness

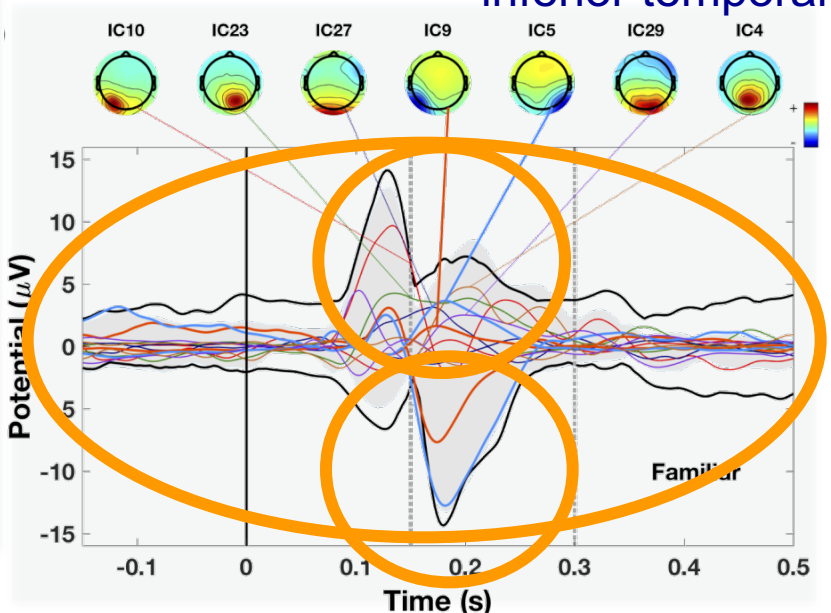
Knowing

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





Face area in bilateral inferior temporal cortex



S. Makeig (2017)

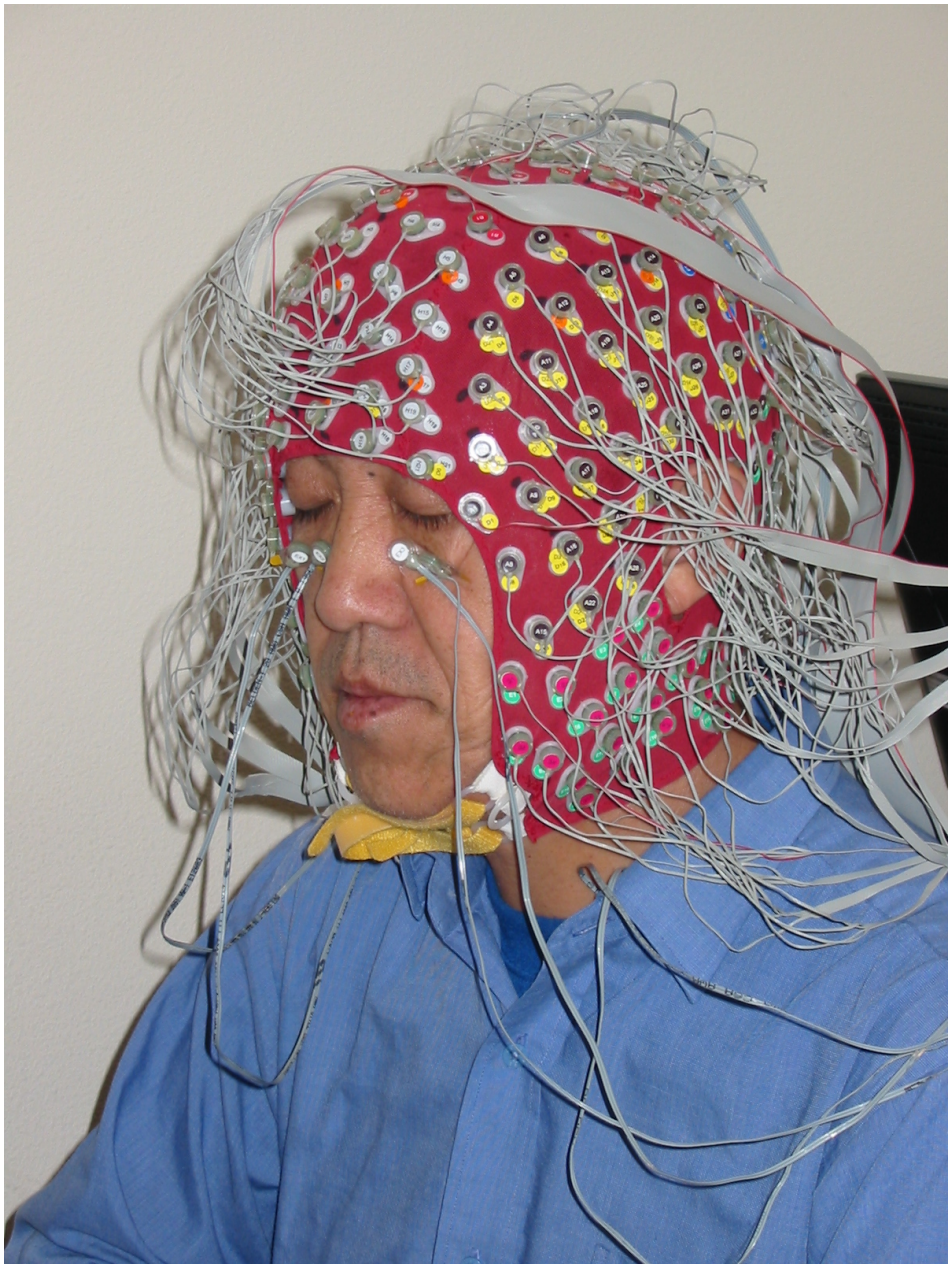
Feeling

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

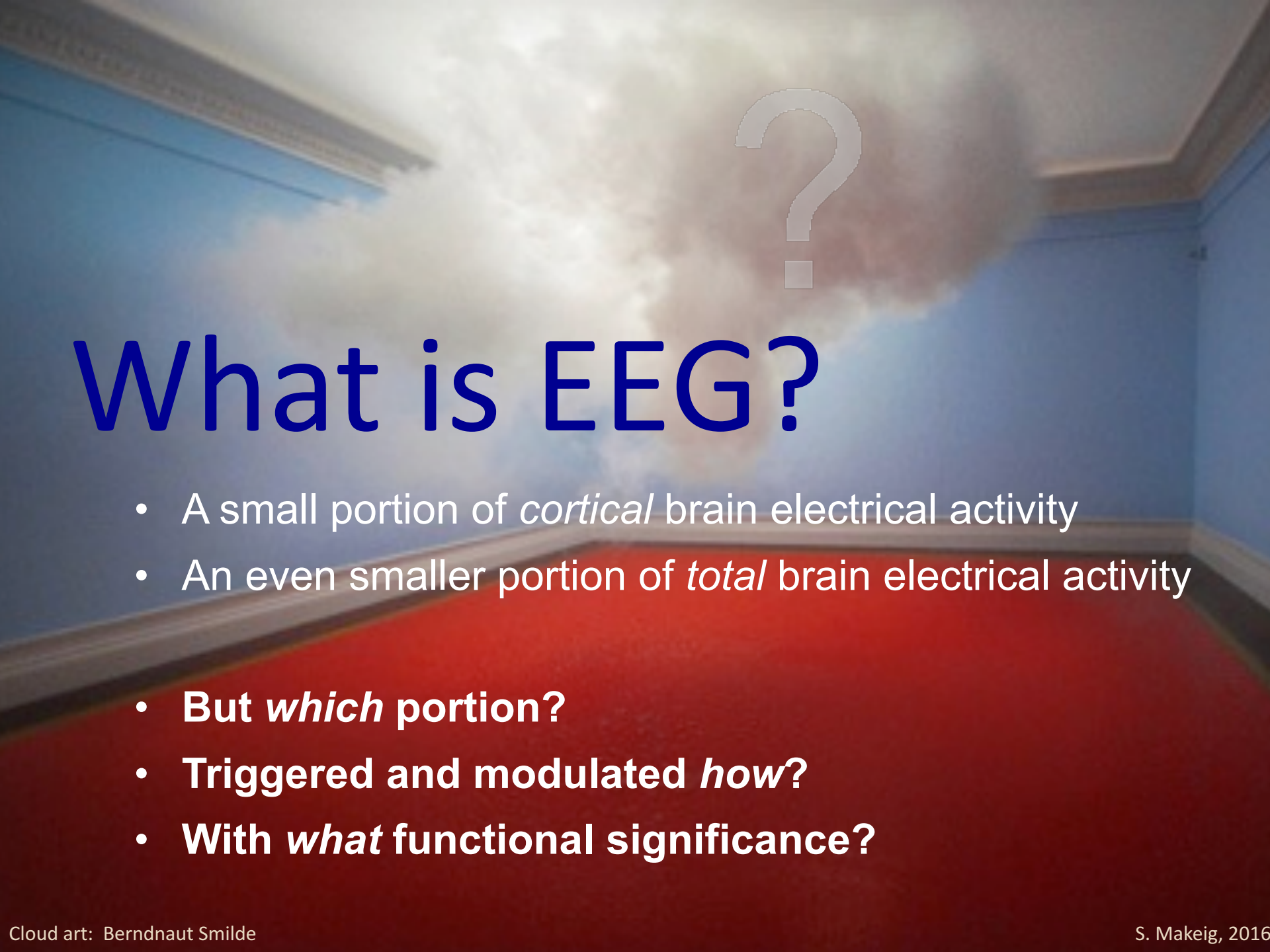


Onton & Makeig, 2009

Willing

Imaging Human Agency

S . Makeig, 2007



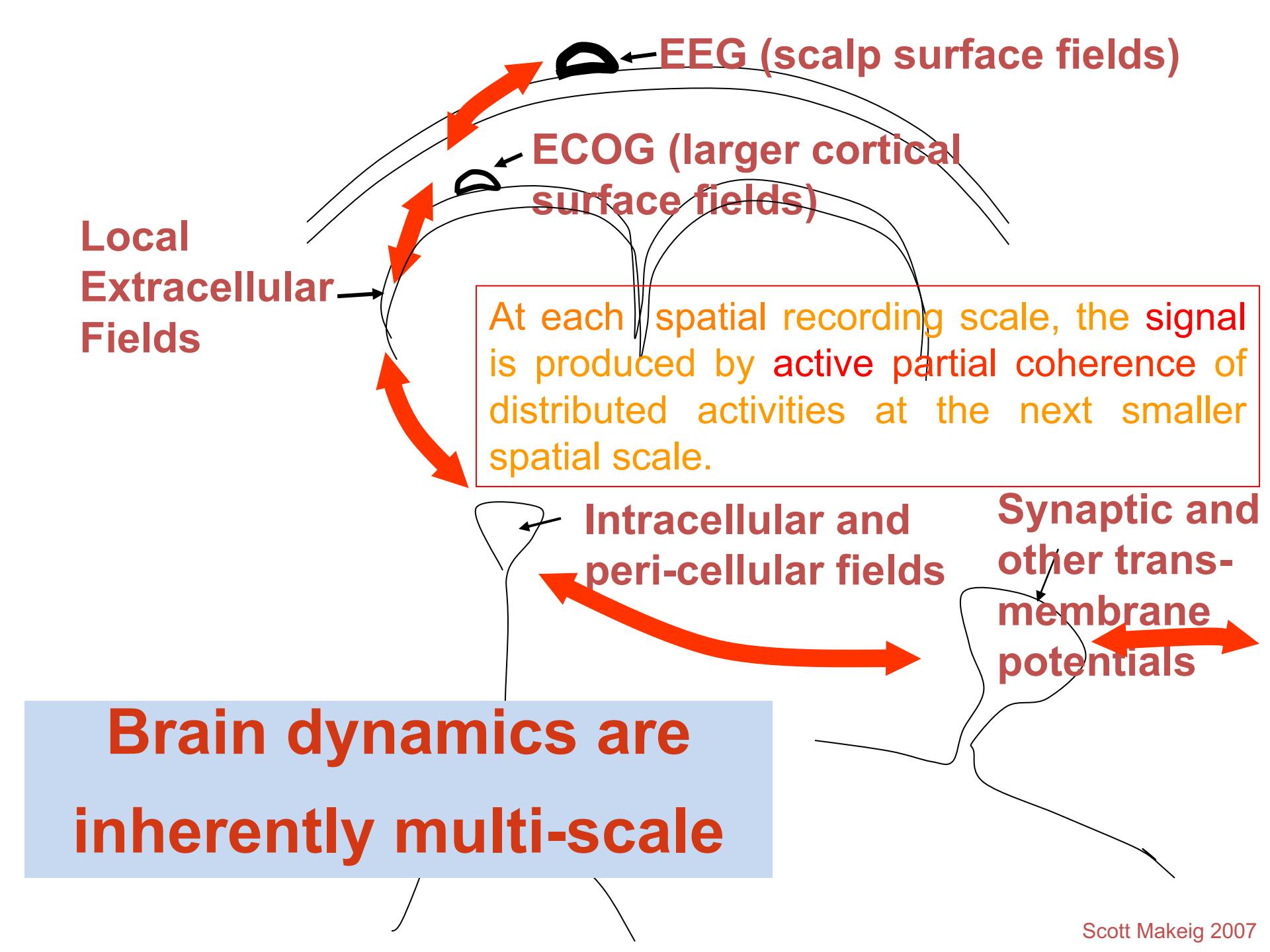
What is EEG?

- 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 Smilde

S. Makeig, 2016



Scott Makeig 2007

Brain dynamics are

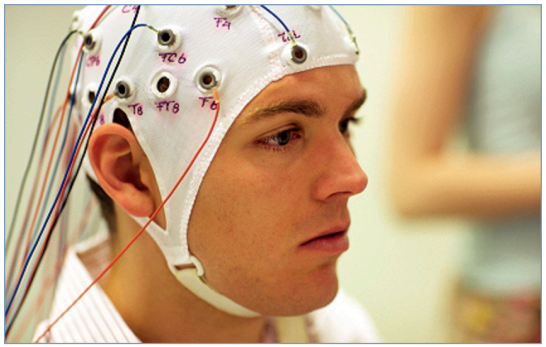
YaleNews

For the Media | Your Yale Search

ARTS & HUMANITIES BUSINESS, LAW, SOCIETY CAMPUS & COMMUNITY SCIENCE & HEALTH

Yale Study Shows Electrical Fields Influence Brain Activity

July 14, 2010



Neuronal activity is measured by EEG. Now it appears that electrical fields influence behavior of brain cells.

Most scientists have viewed electrical fields within the brain as the simple byproducts of neuronal activity. However, Yale scientists report in the July 15 issue of the journal Neuron that electrical fields can also influence the activity of brain cells.

The finding helps explain why techniques that influence electrical fields such as transcranial magnetic stimulation and deep brain stimulation are effective for the treatment of various neurological disorders, including depression. The study also "raises many questions about the possible effects of electrical fields, such as power lines and cell phones, in which we immerse ourselves," said David McCormick, the Dorys McConnell Duberg Professor of Neurobiology at Yale School of Medicine, a researcher of the Kavli Institute of Neuroscience and senior author of the study.

The chemical process that triggers tiny charges in the membranes of neurons causes much of the brain's electrical activity. Electroencephalograms, or EEGs, detect these fluctuations when they occur in large numbers of neurons together. These internal electrical signals contain information about certain cognitive and behavioral states but, until now, it had not been shown whether they actually change the activity of the brain itself.

McCormick and Flavio Frohlich, a postdoctoral research associate, introduced slow oscillation signals into brain tissue and found that the signal created a sort of feedback loop, with changes in electrical field guiding neural activity, which in turn strengthened the electrical field.

"It's like asking whether the roar of the crowd in the football stadium also influences you to cheer as well. And in turn, your cheering encourages others to cheer along with you." McCormick said.

The ability of electric fields generated by the brain to influence its own activity appears to be particularly prominent during epileptic seizures. However, the influence of electric fields is not limited to these pathological states. The study of Frohlich and McCormick demonstrates that the electrical fields also influence brain function during normal activities such as sleep.

McCormick said the findings change the way in which we view brain function and may be of significant clinical value in controlling epilepsy, depression and other neural dysfunctional states.

EEG (scalp surface fields)

(larger cortical
e fields)

spatial recording scale, the signal
ed by active partial coherence of
l activities at the next smaller
ale.

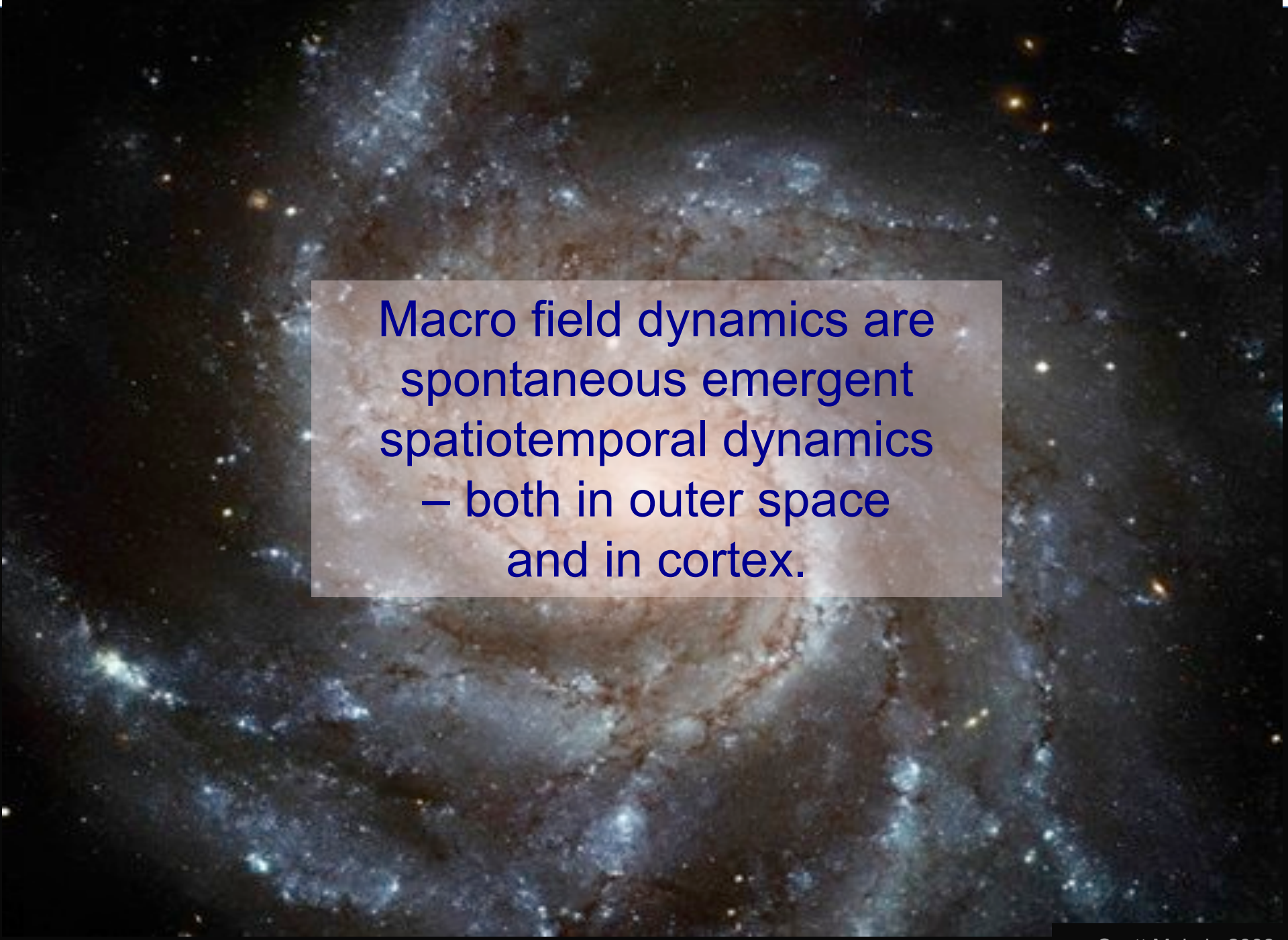
acellular and
-cellular fields

Synaptic and
other trans-
membrane
potentials

Scott Makeig 2007

Macro field dynamics are spontaneous emergent spatiotemporal dynamics

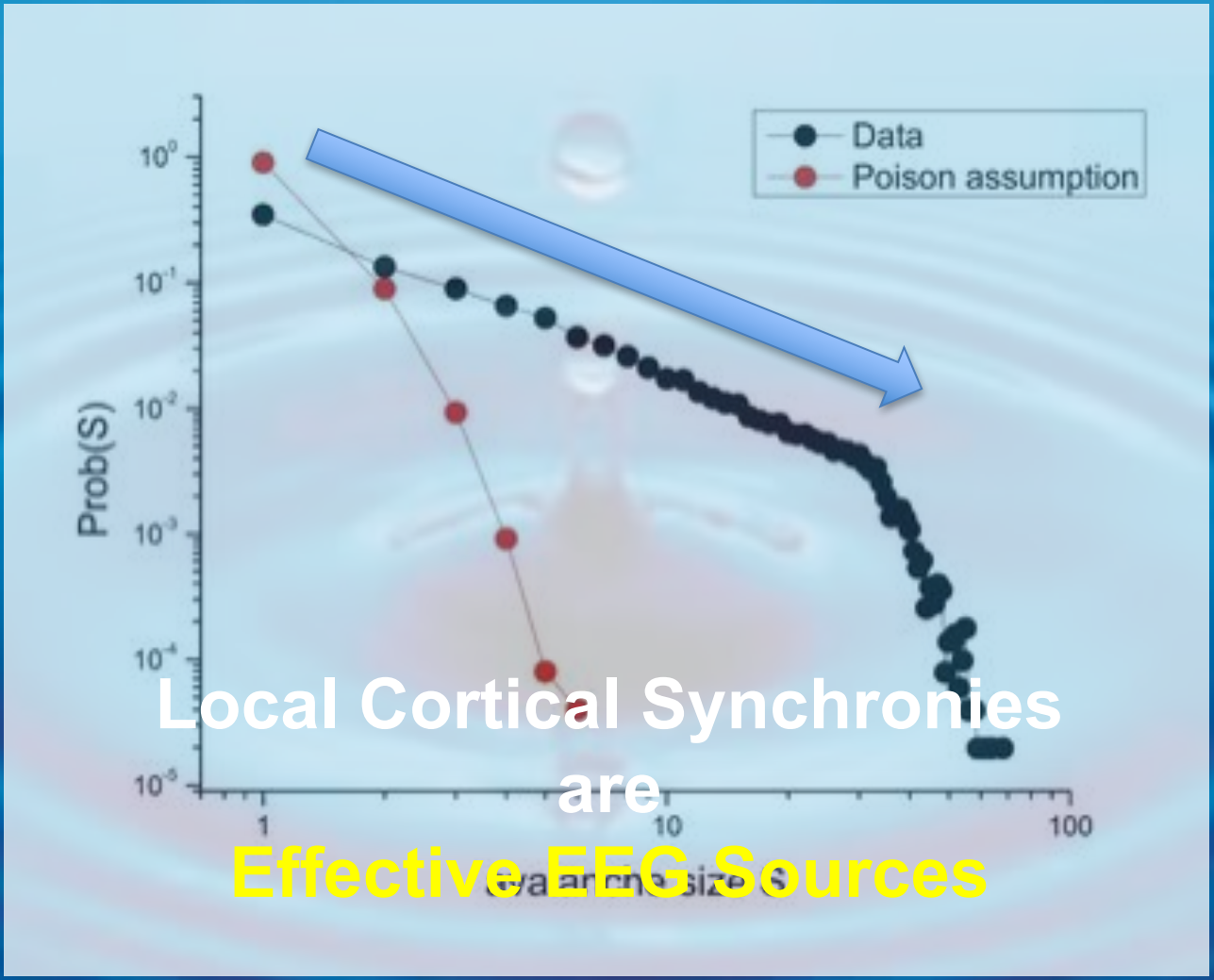
– both in outer space and in cortex.


Macro field dynamics are
spontaneous emergent
spatiotemporal dynamics
– both in outer space
and in cortex.

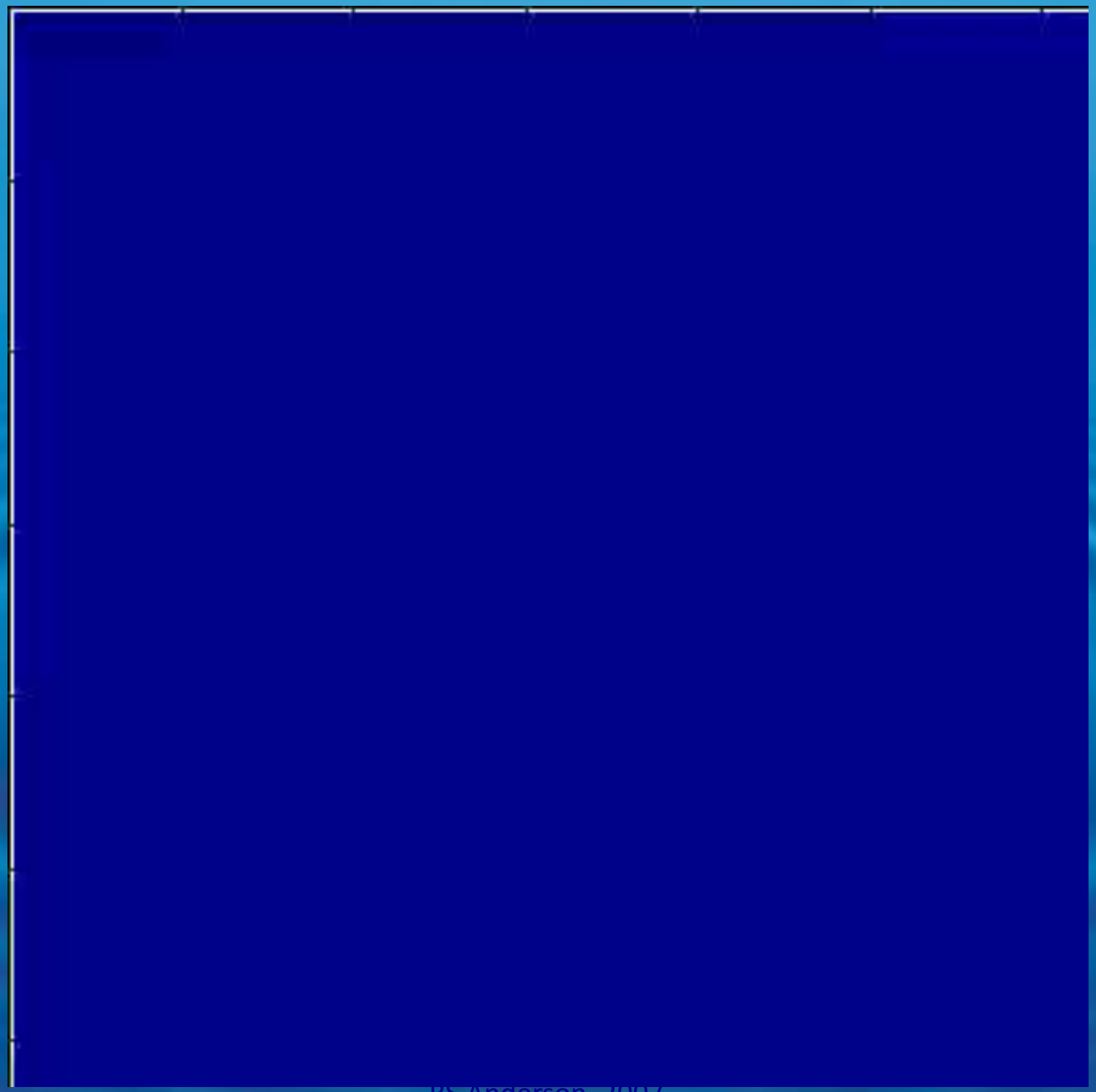
Phase cones (Freeman)

Avalanches (Plenz)

= Avalanches (Beggs & Plenz)



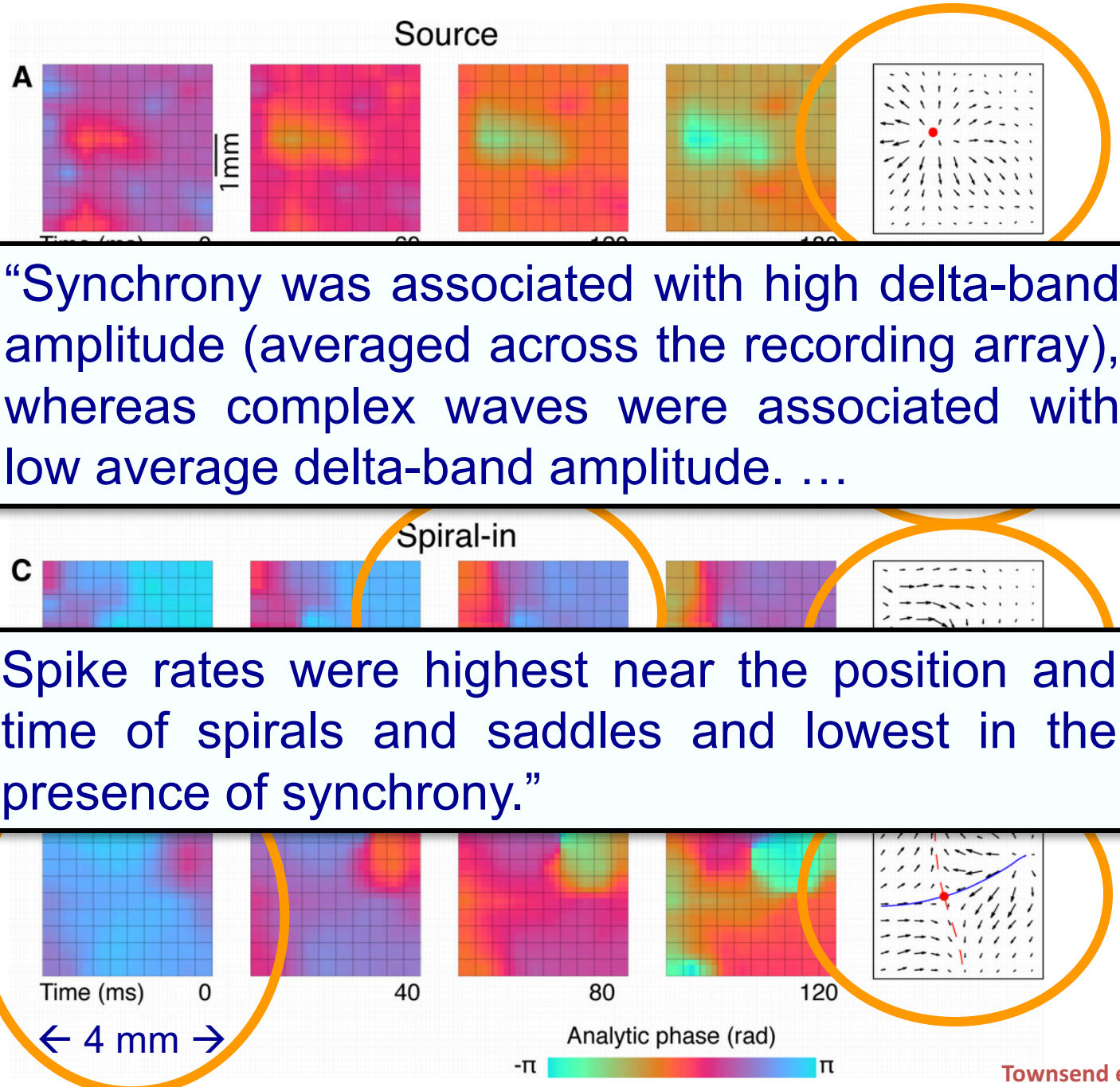
S. Makeig 2007



RS Anderson, 2007

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

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



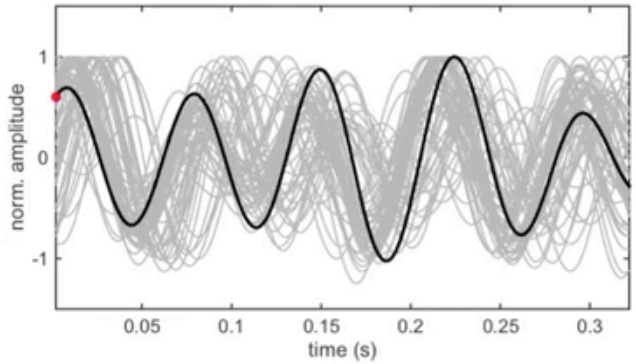
"Synchrony was associated with high delta-band amplitude (averaged across the recording array), whereas complex waves were associated with low average delta-band amplitude. …

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

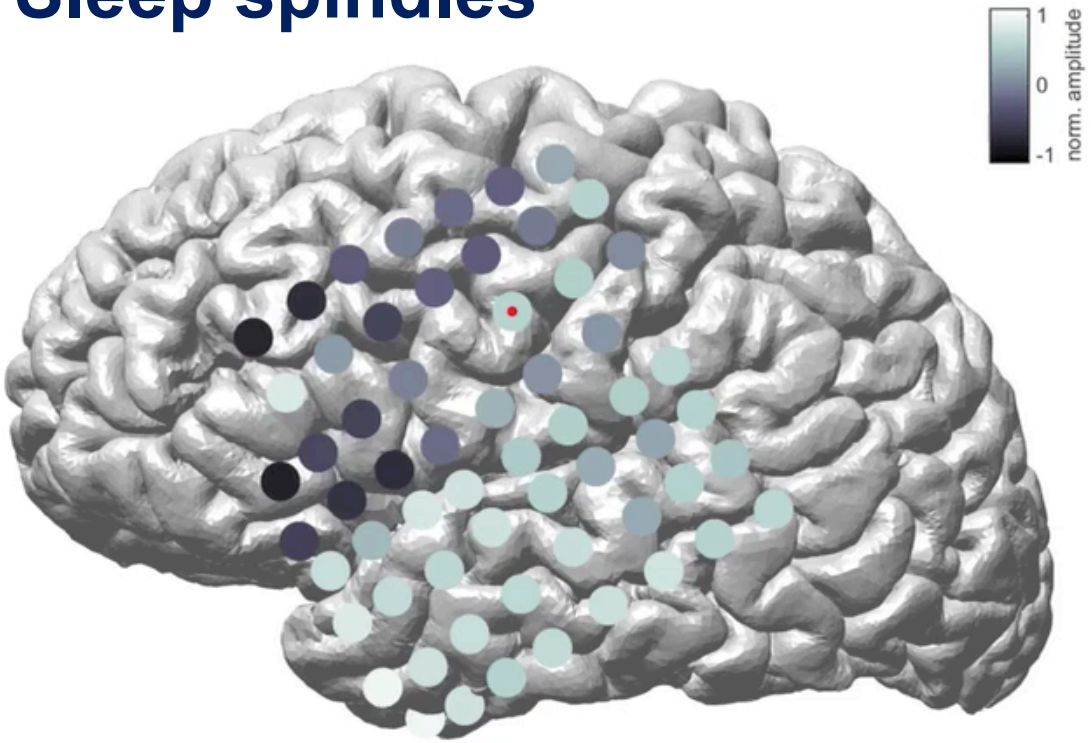
Simple patterns

Complex patterns

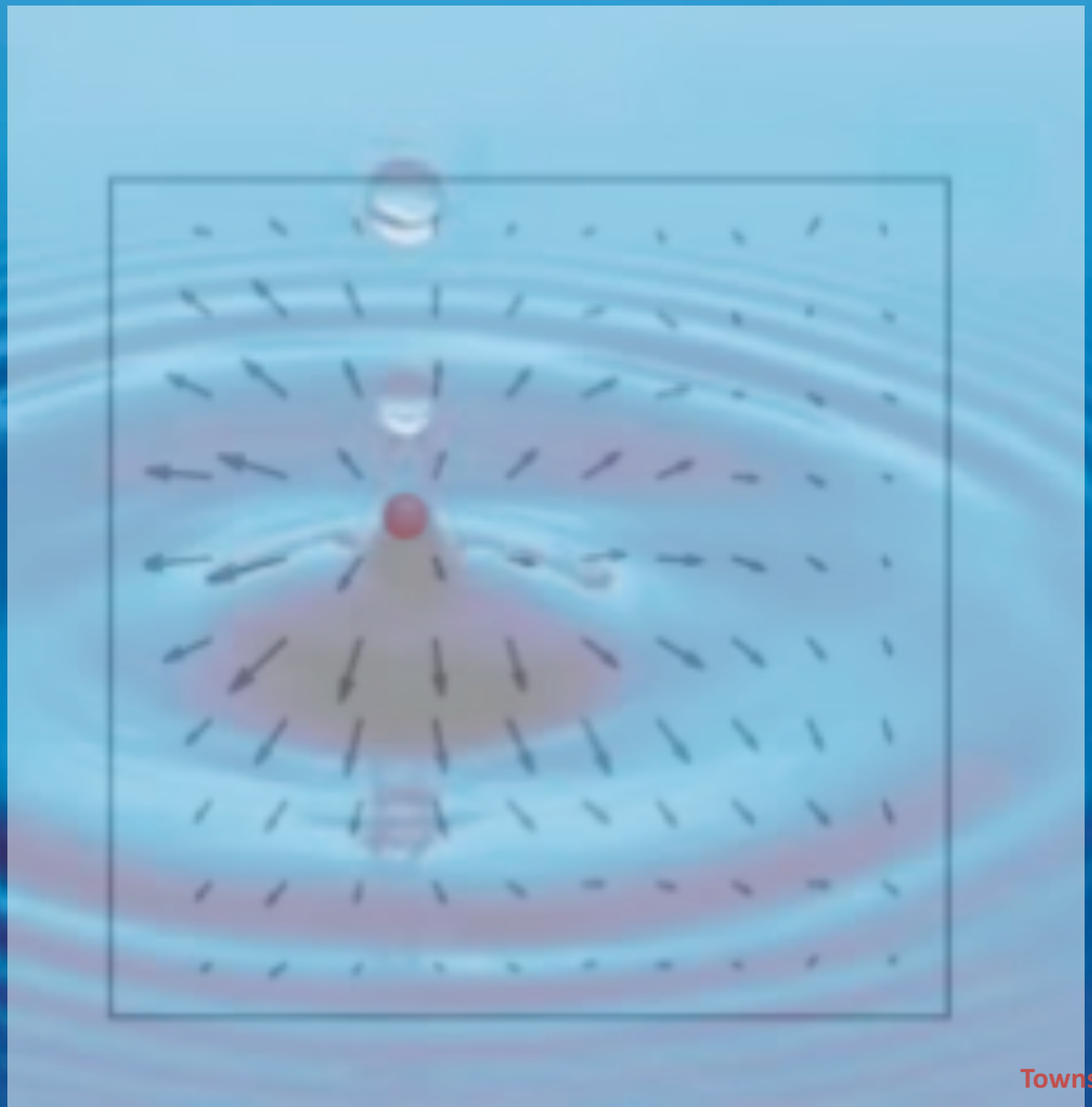
Townsend et al., 2015



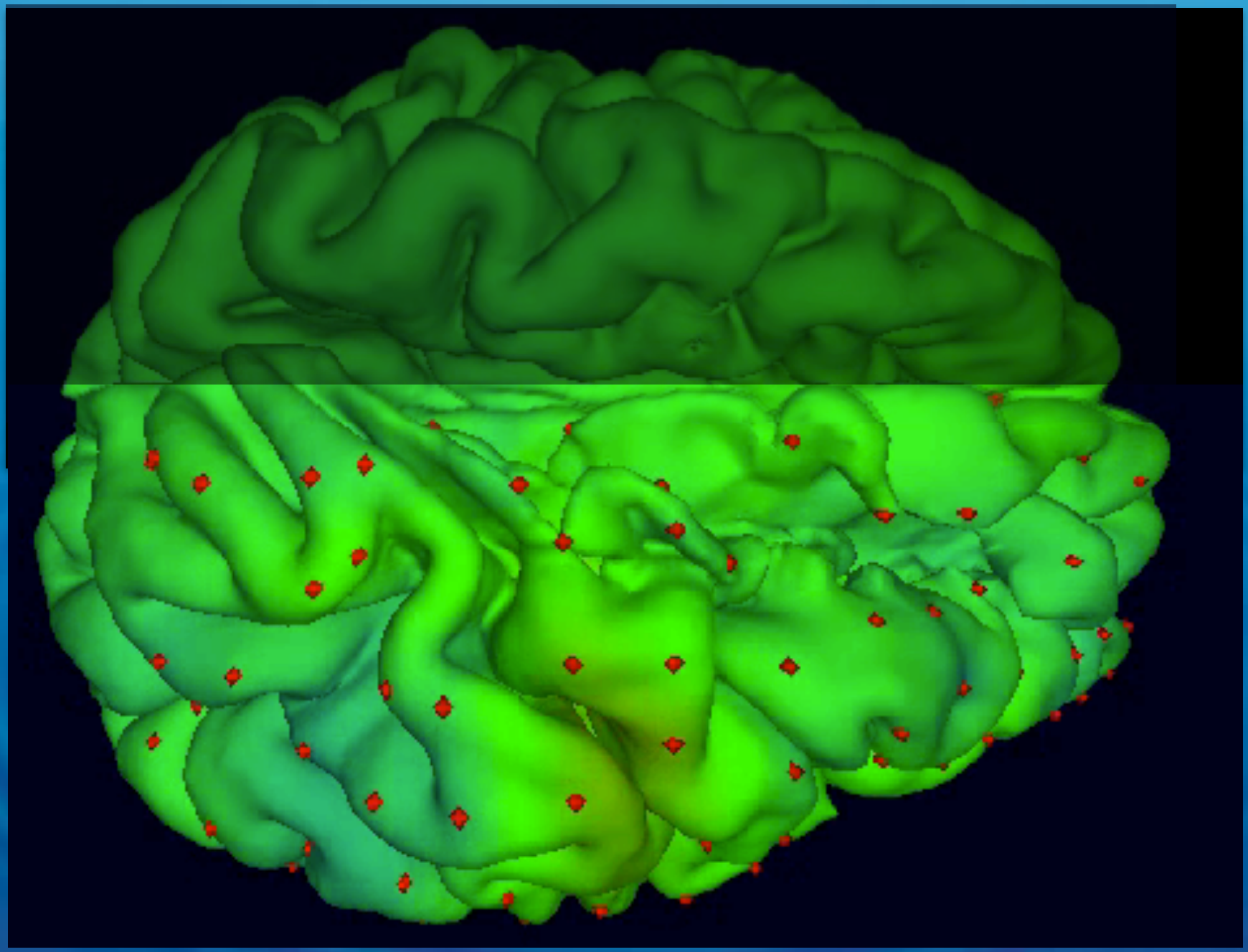
Sleep spindles



Muller et al., 2014



Townsend et al., 2015

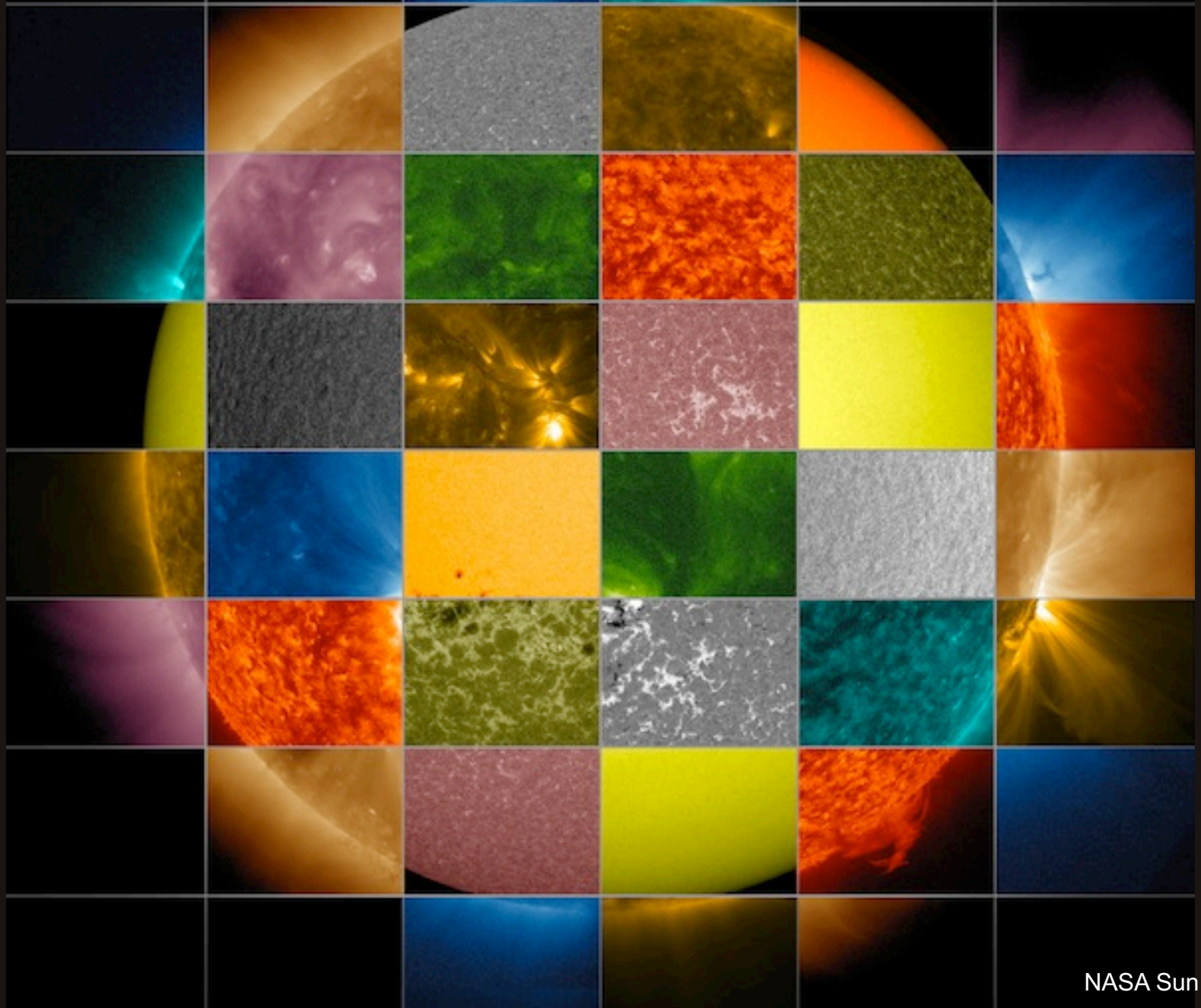


Z Akalin Acar, 2017

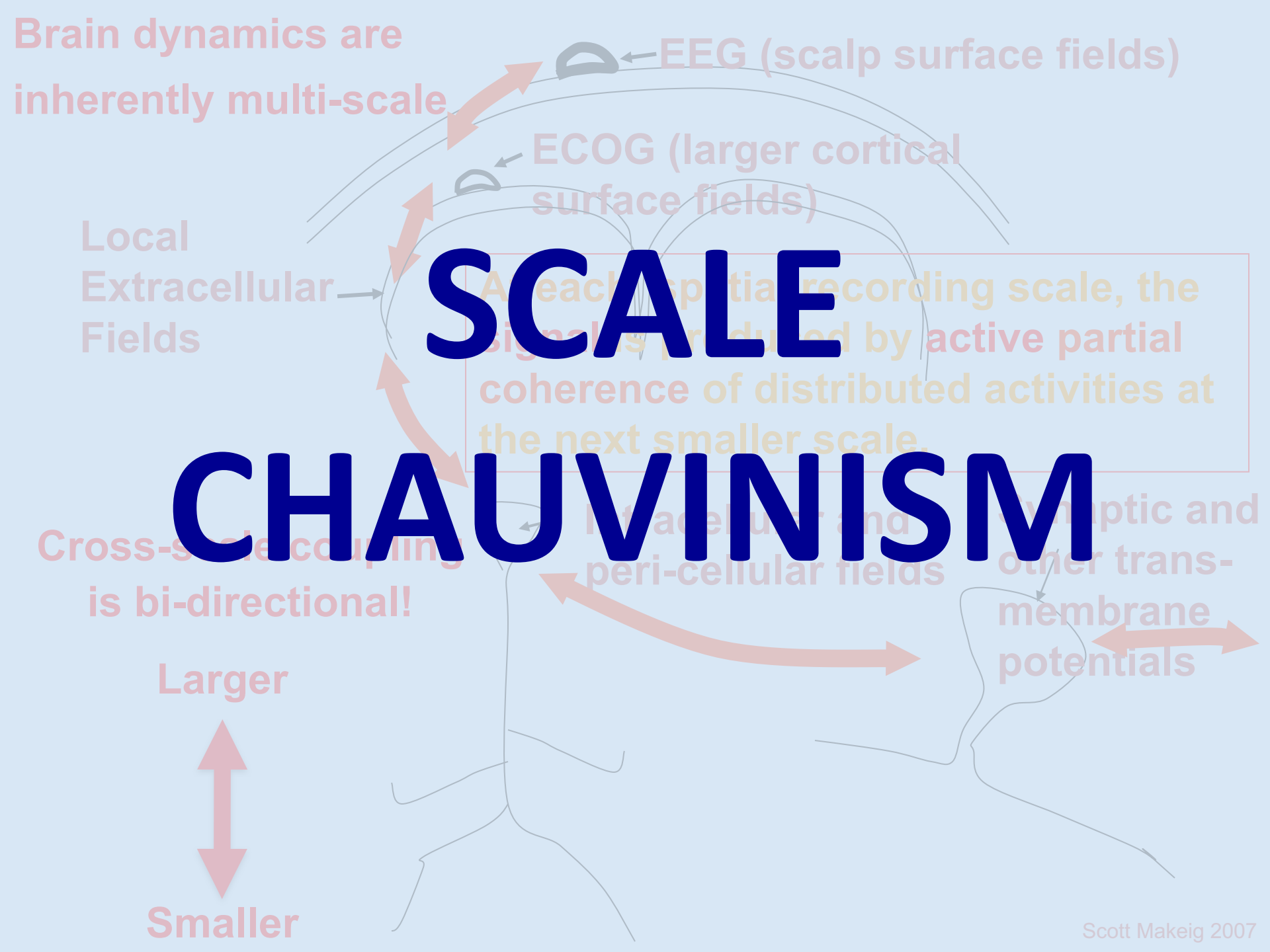
The spatiotemporal field dynamics of cortex and brain have not yet been imaged on multiple spatial scales!

Alan Friedman

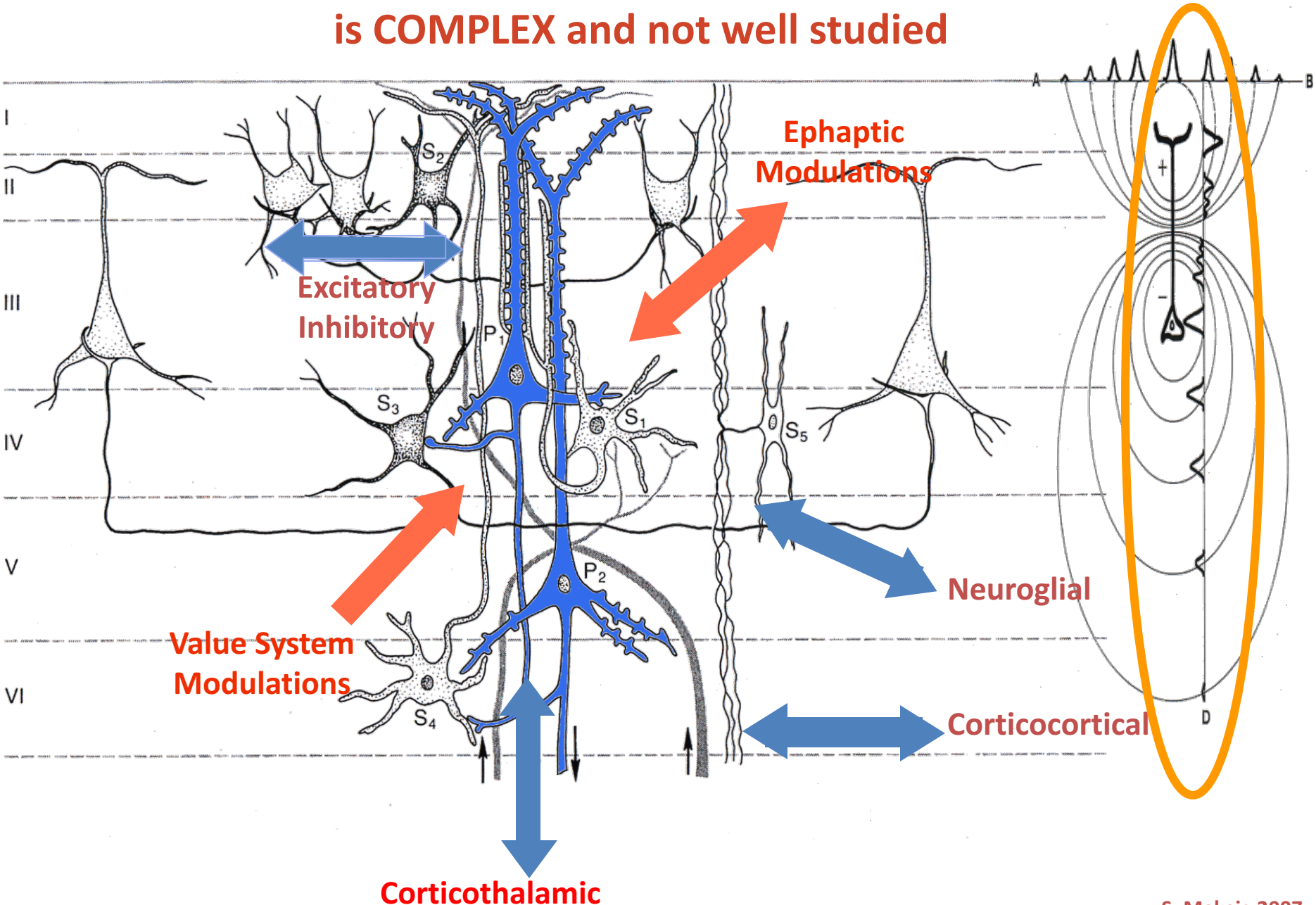
Spatial complexity involves frequency



NASA Sun Observatory


Brain dynamics are inherently multi-scale
EEG (scalp surface fields)
ECOG (larger cortical surface fields)
Local Extracellular Fields
At each spatial recording scale, the signals are produced by active partial coherence of distributed activities at the next smaller scale.
SCALE CHAUVINISM
Cross-scale coupling is bi-directional!
Intracellular and peri-cellular fields
Synaptic and other trans-membrane potentials
Larger
Smaller
Scott Makeig 2007

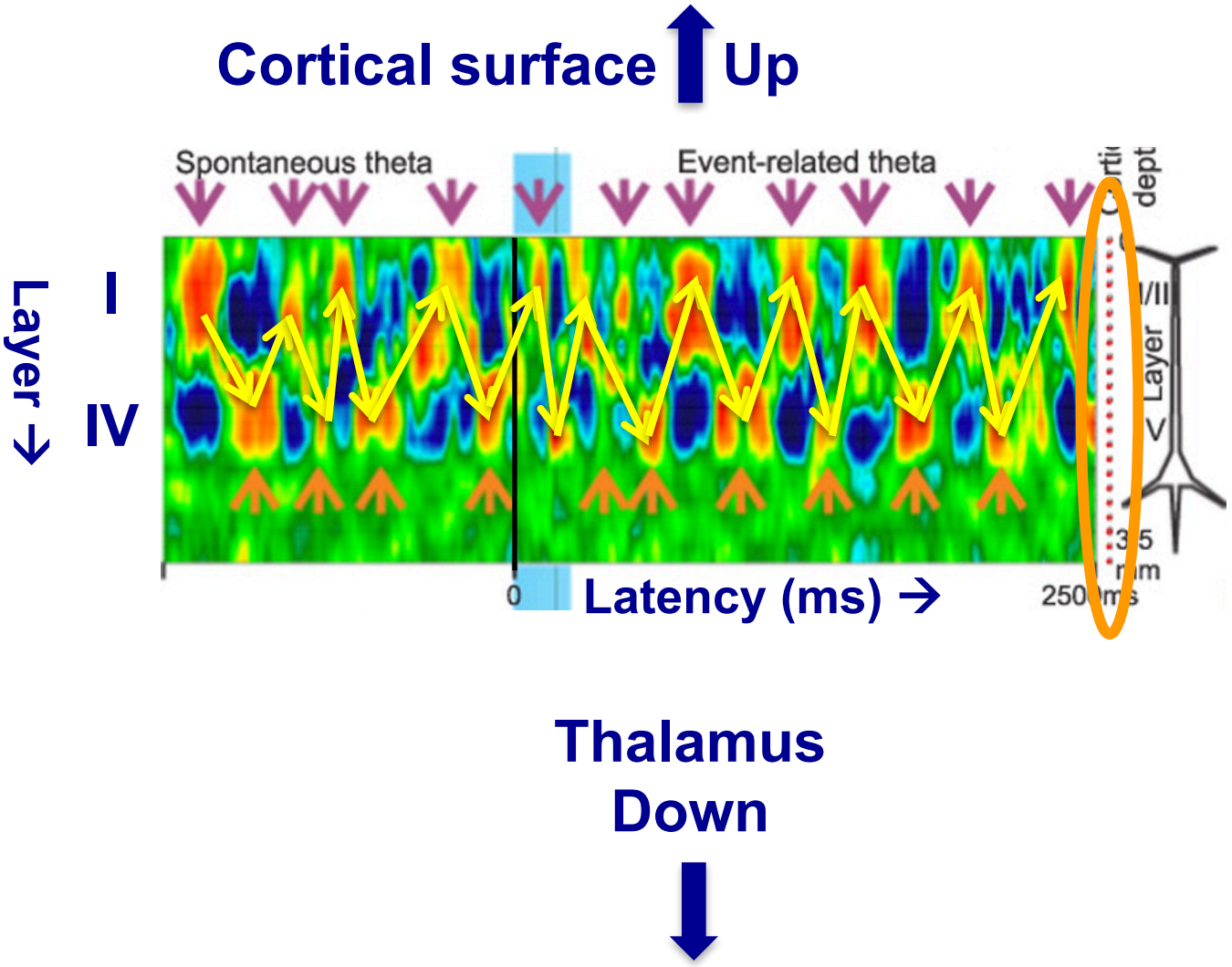
The generation and modulation of EEG is COMPLEX and not well studied

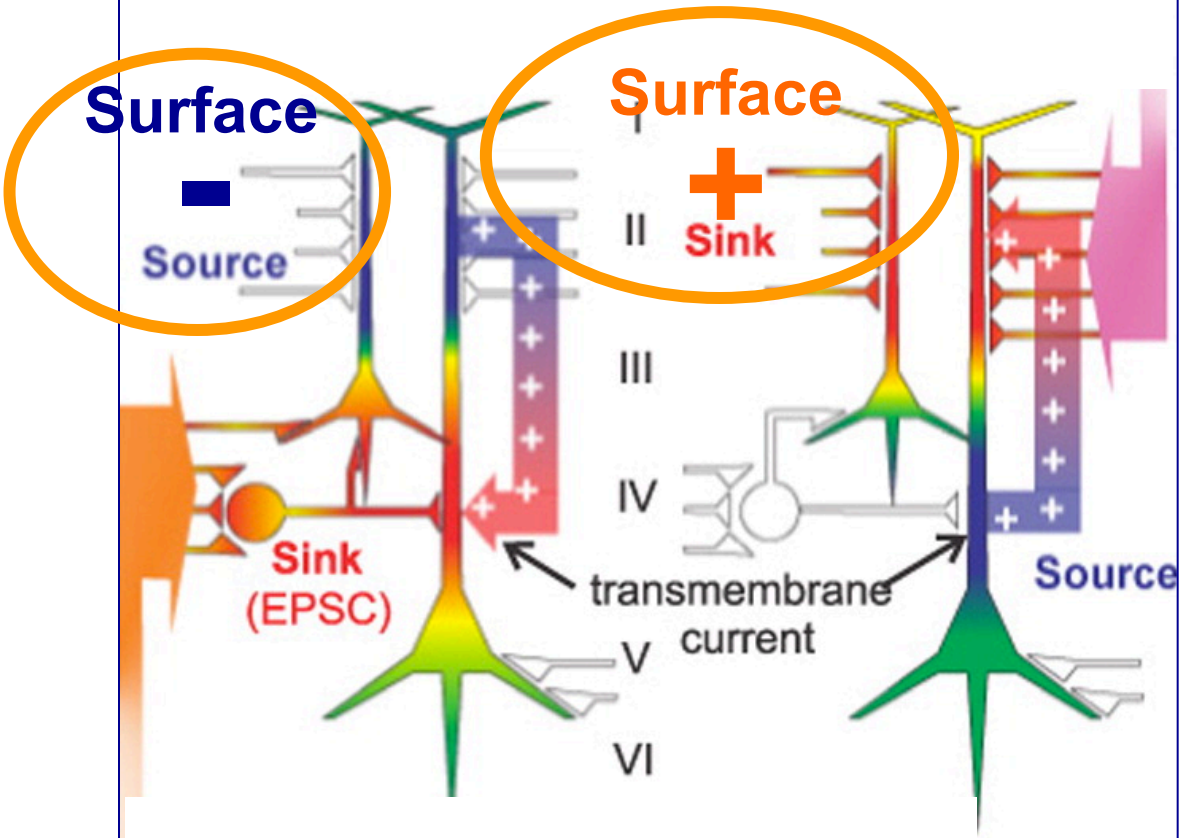


S. Makeig 2007

In Cortex: Up ≠ Down

(and +μV ≠ -μV)



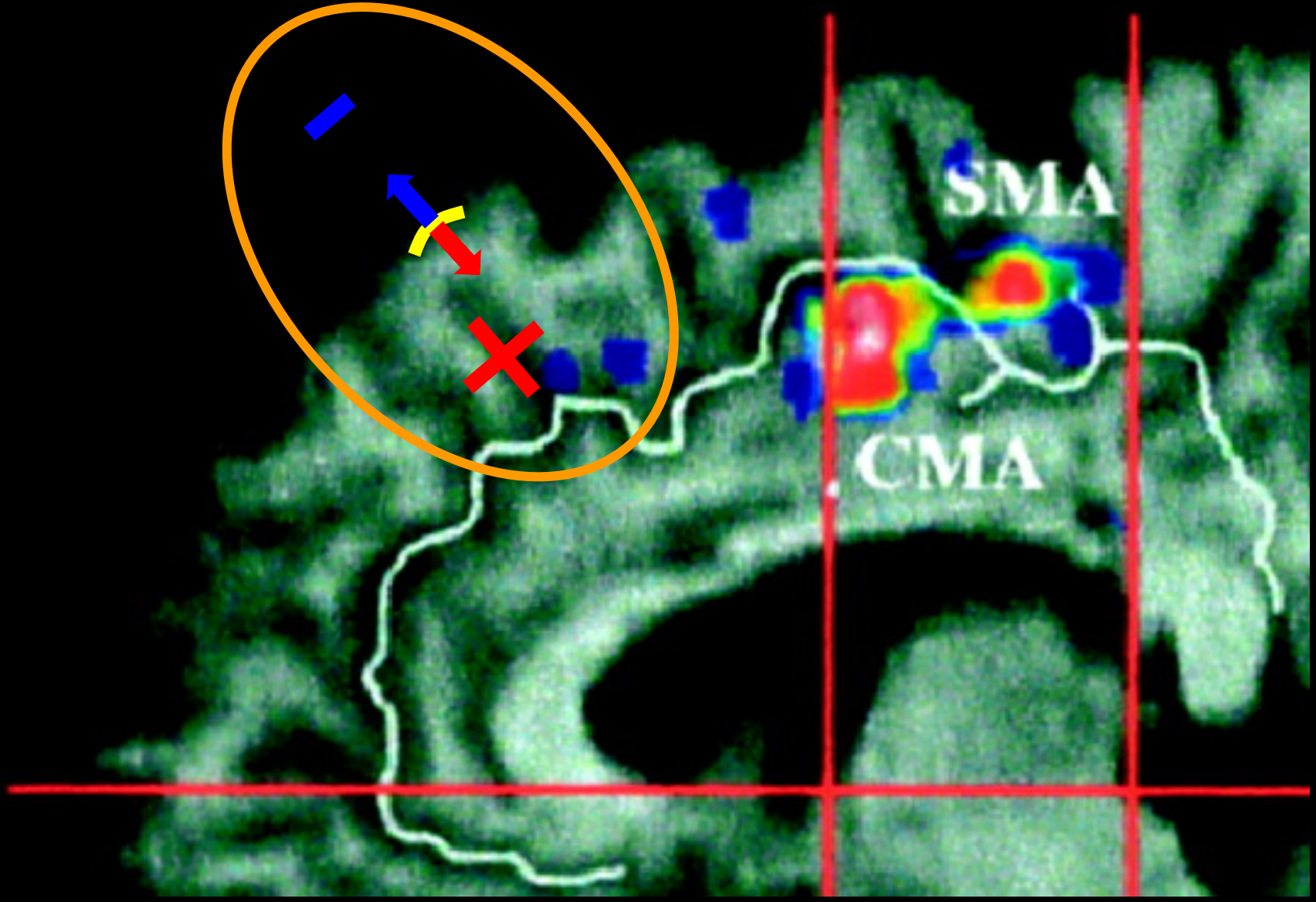


From E. Halgren et al., 2015

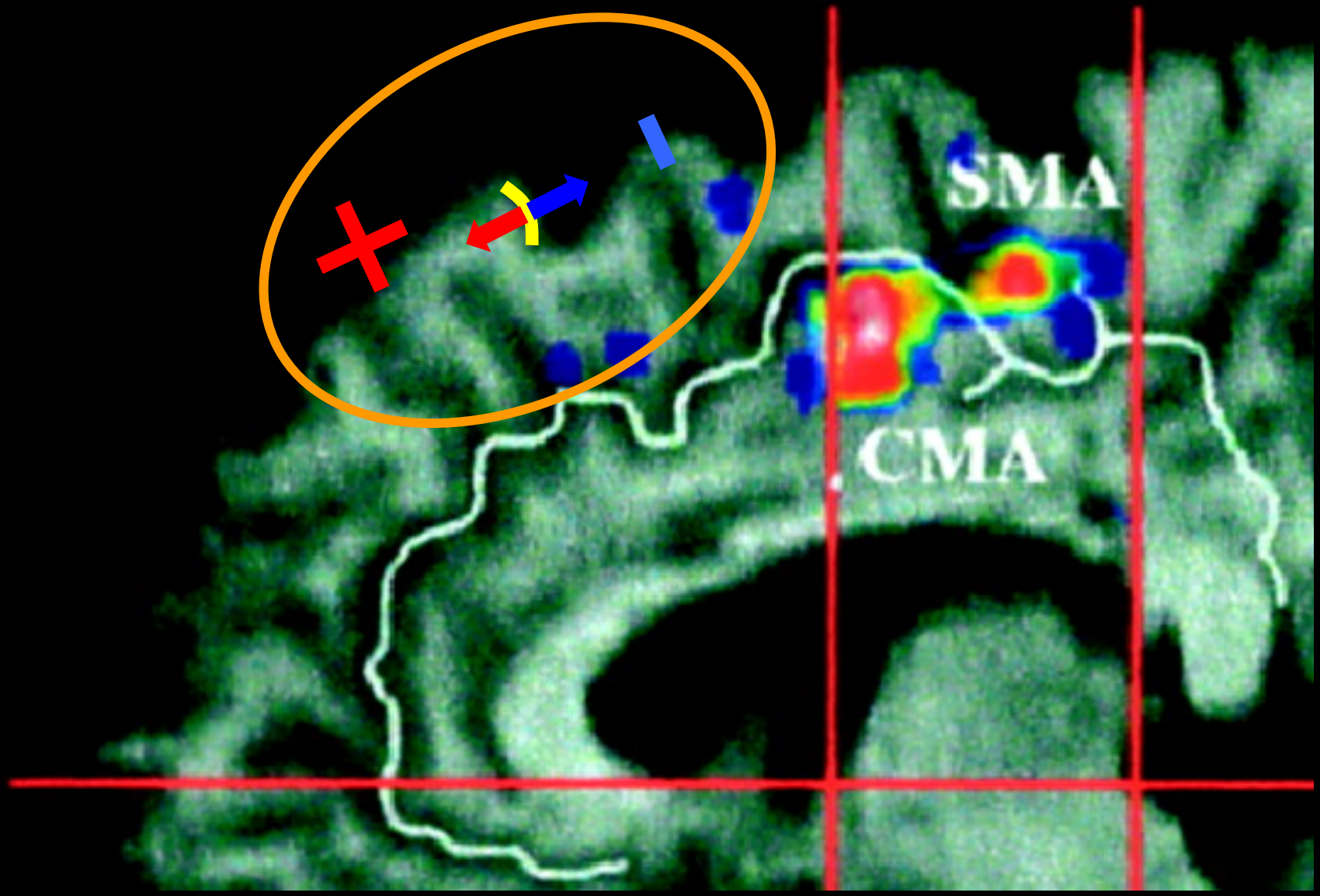
(see T. Elbert, ~1990)

Slide: S. Makeig, 2016

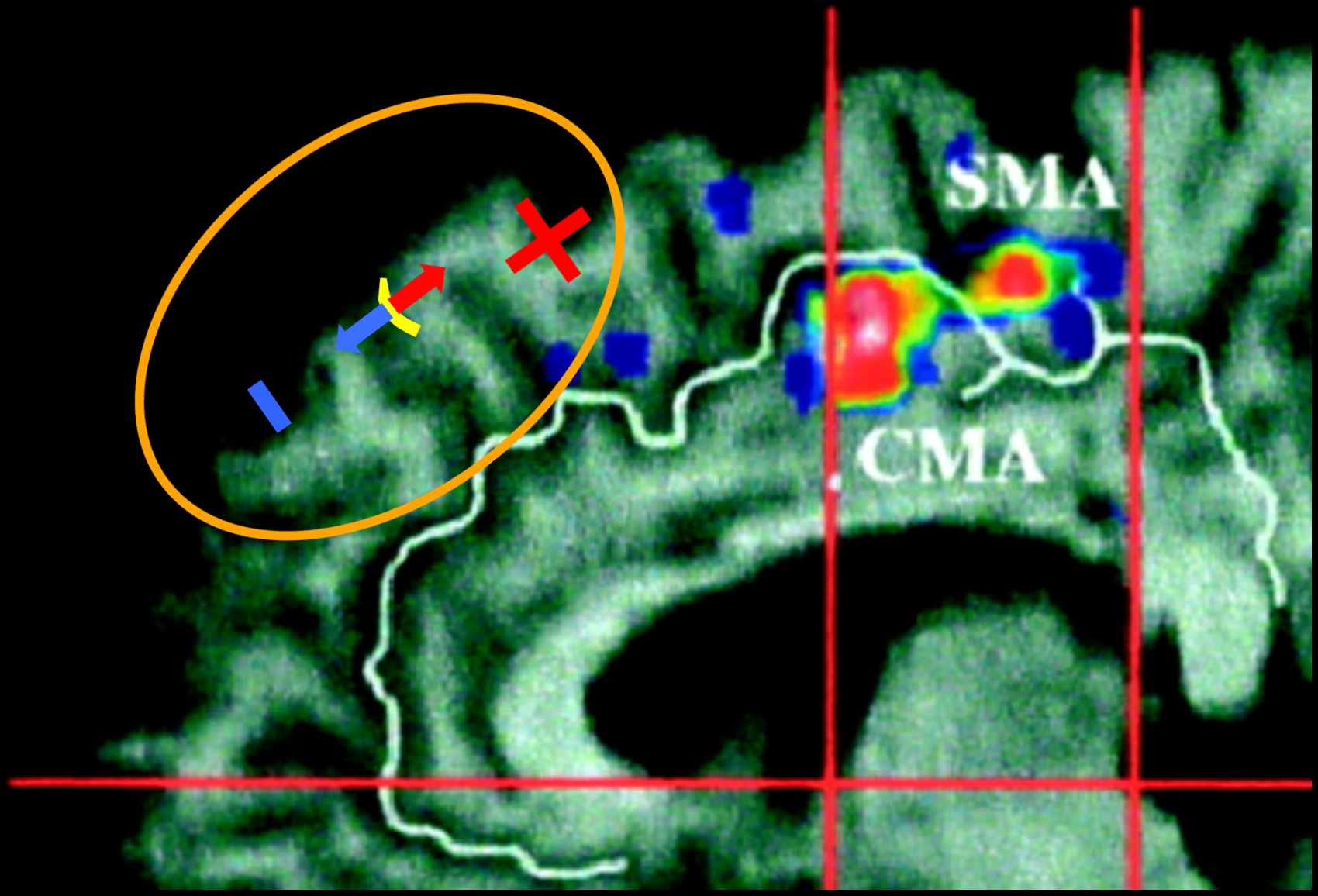
Cortical Up ≠ Towards the Scalp



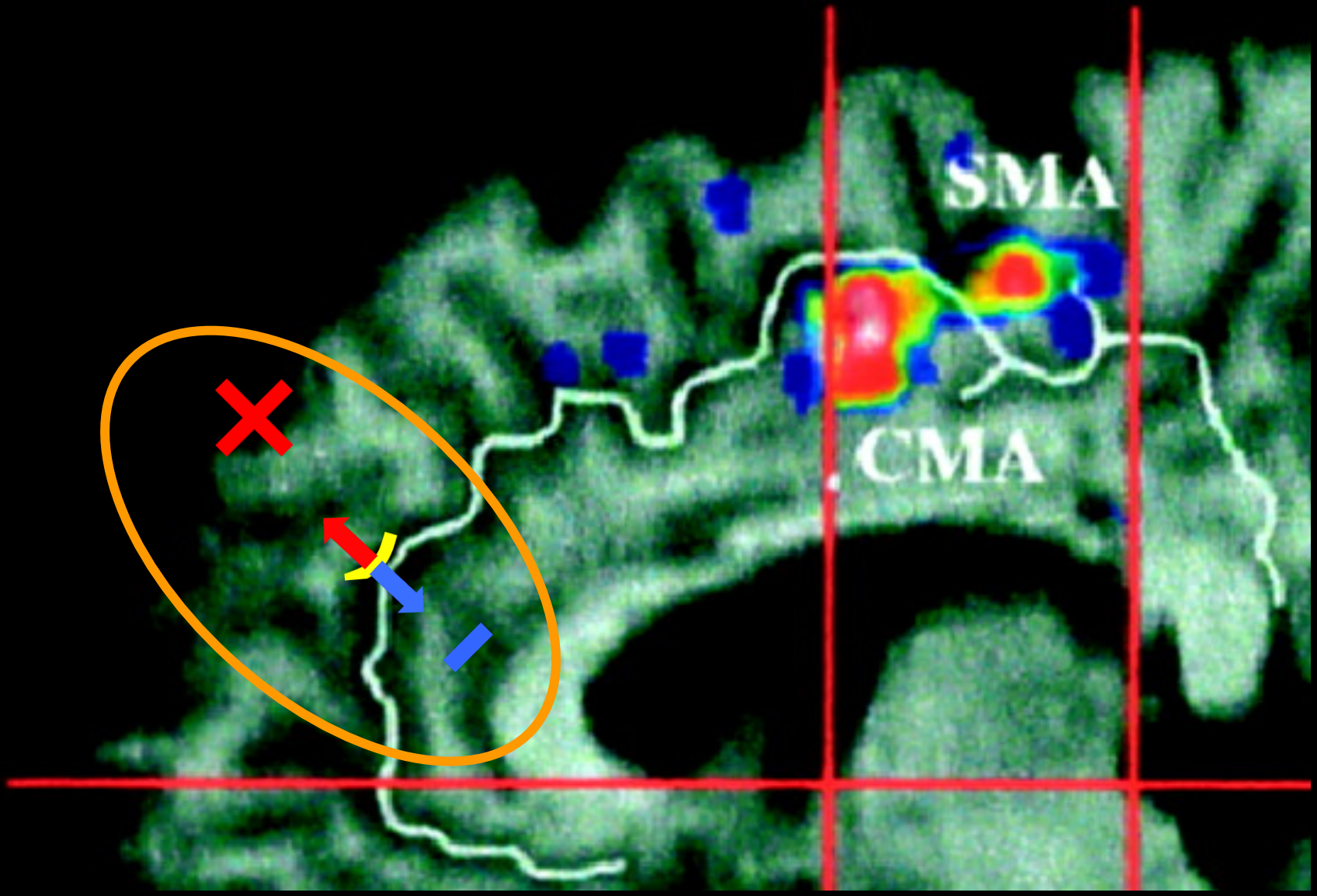
Cortical Up ≠ Towards the Scalp



Cortical Up ≠ Towards the Scalp

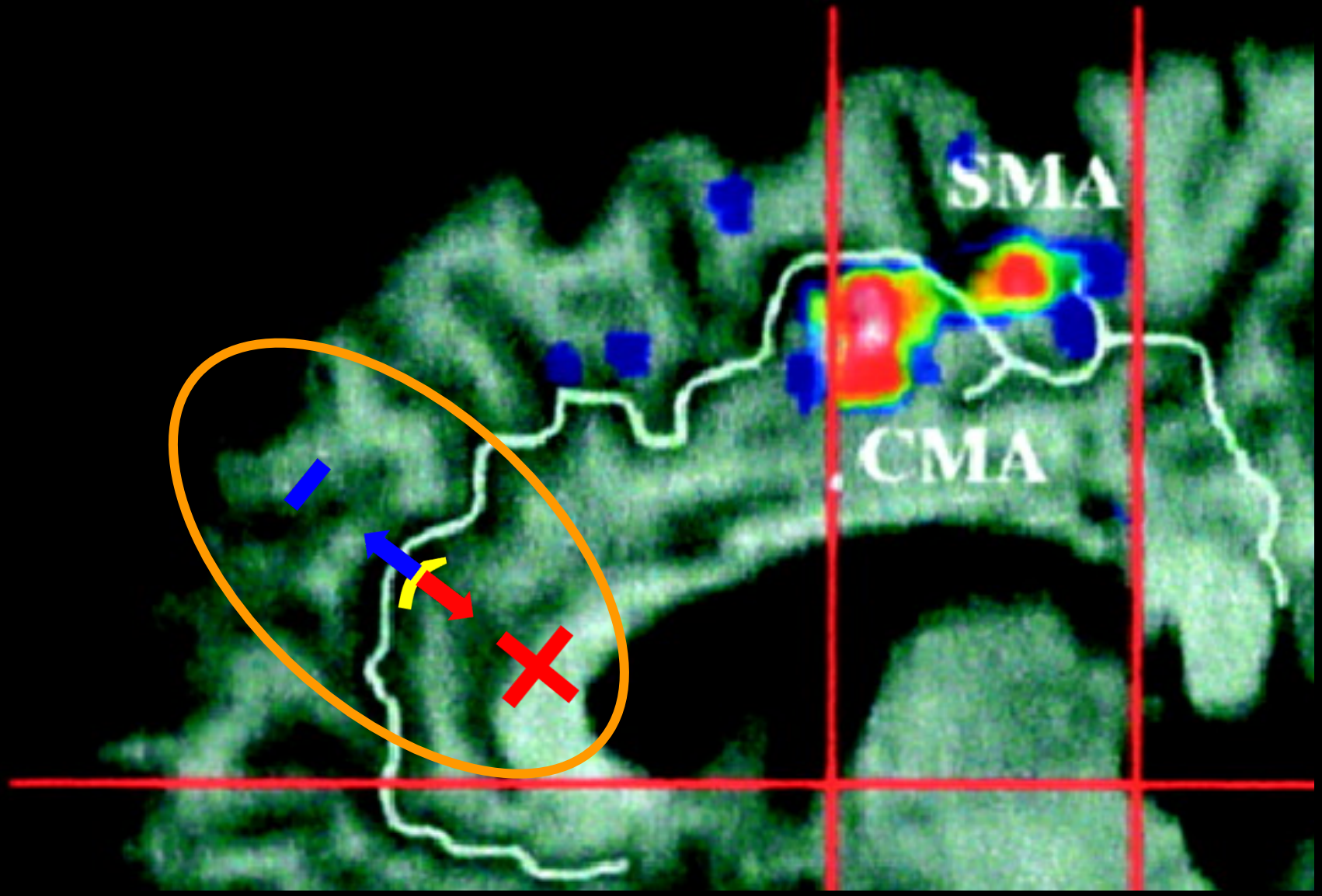


Cortical Up ≠ Towards the Scalp



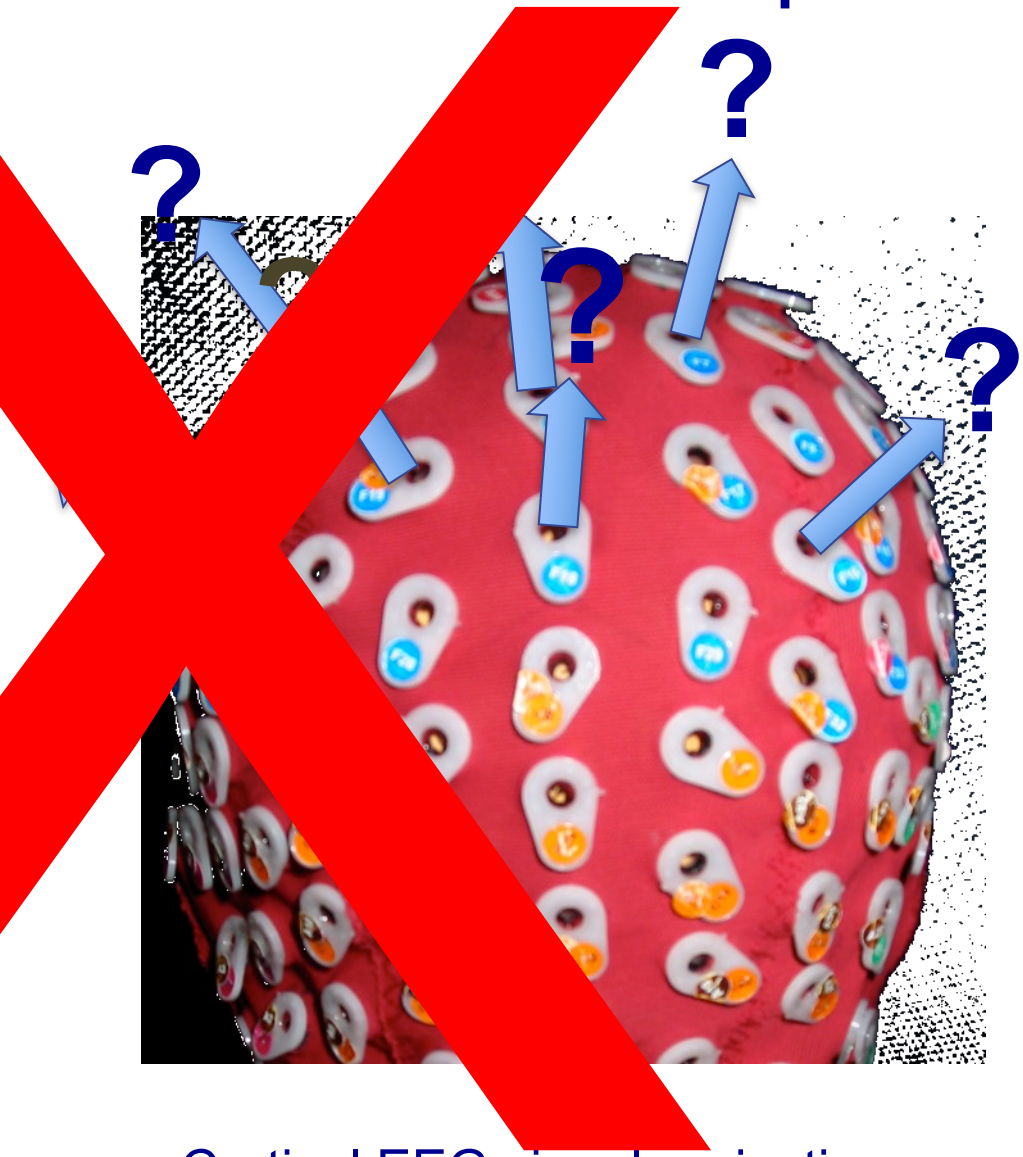
Slide: S. Makeig, 2017

Cortical Up ≠ Towards the Scalp

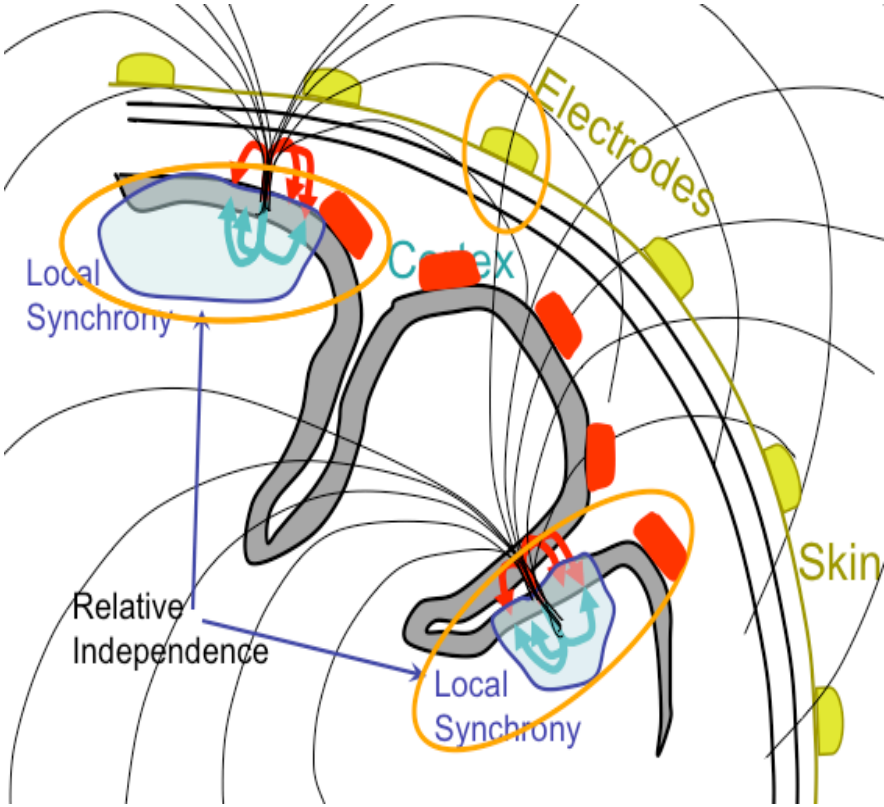


Slide: S. Makeig, 2017

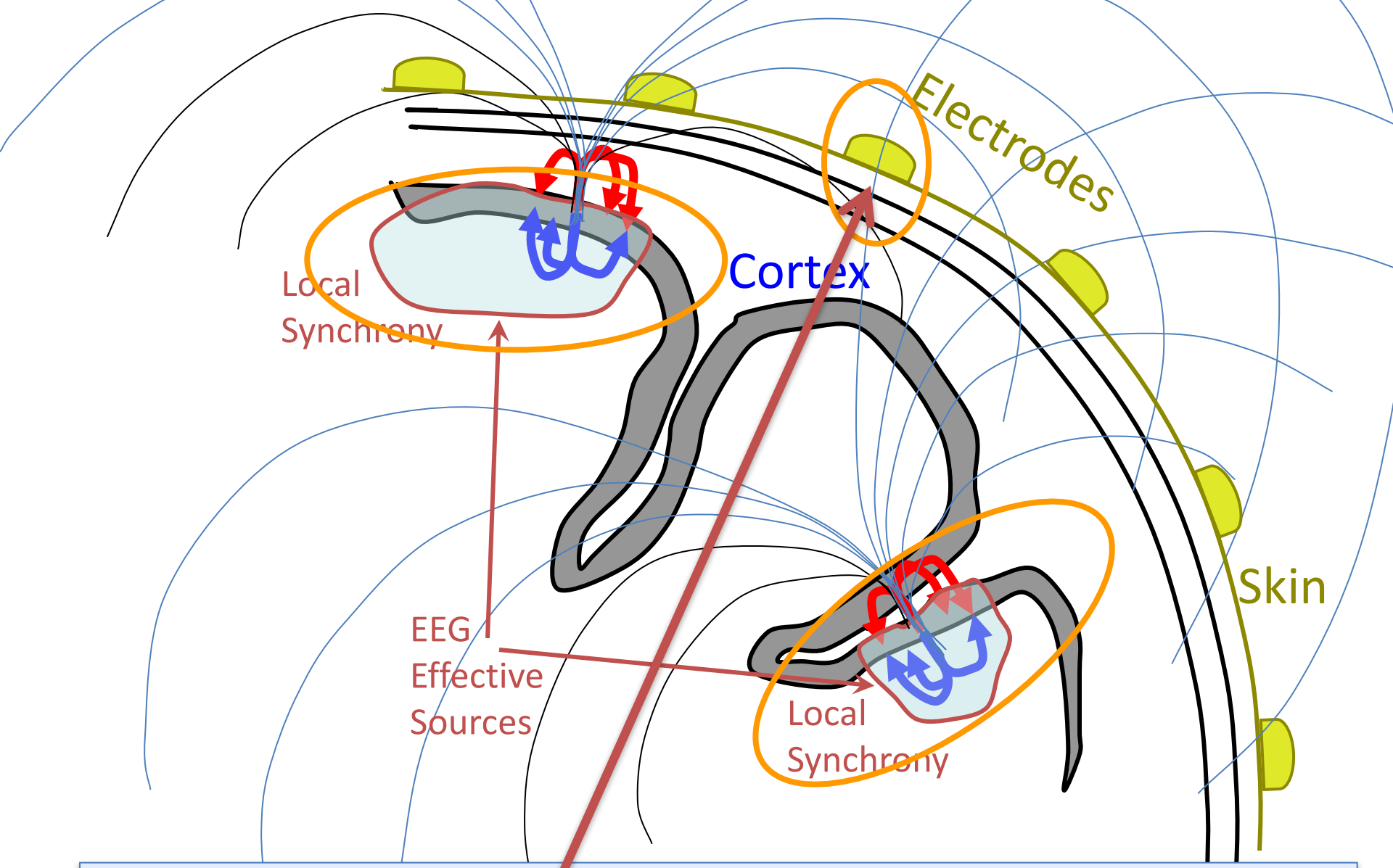
Naïve 2-D interpretation of EEG signals?



Cortical EEG signal projection patterns as point processes



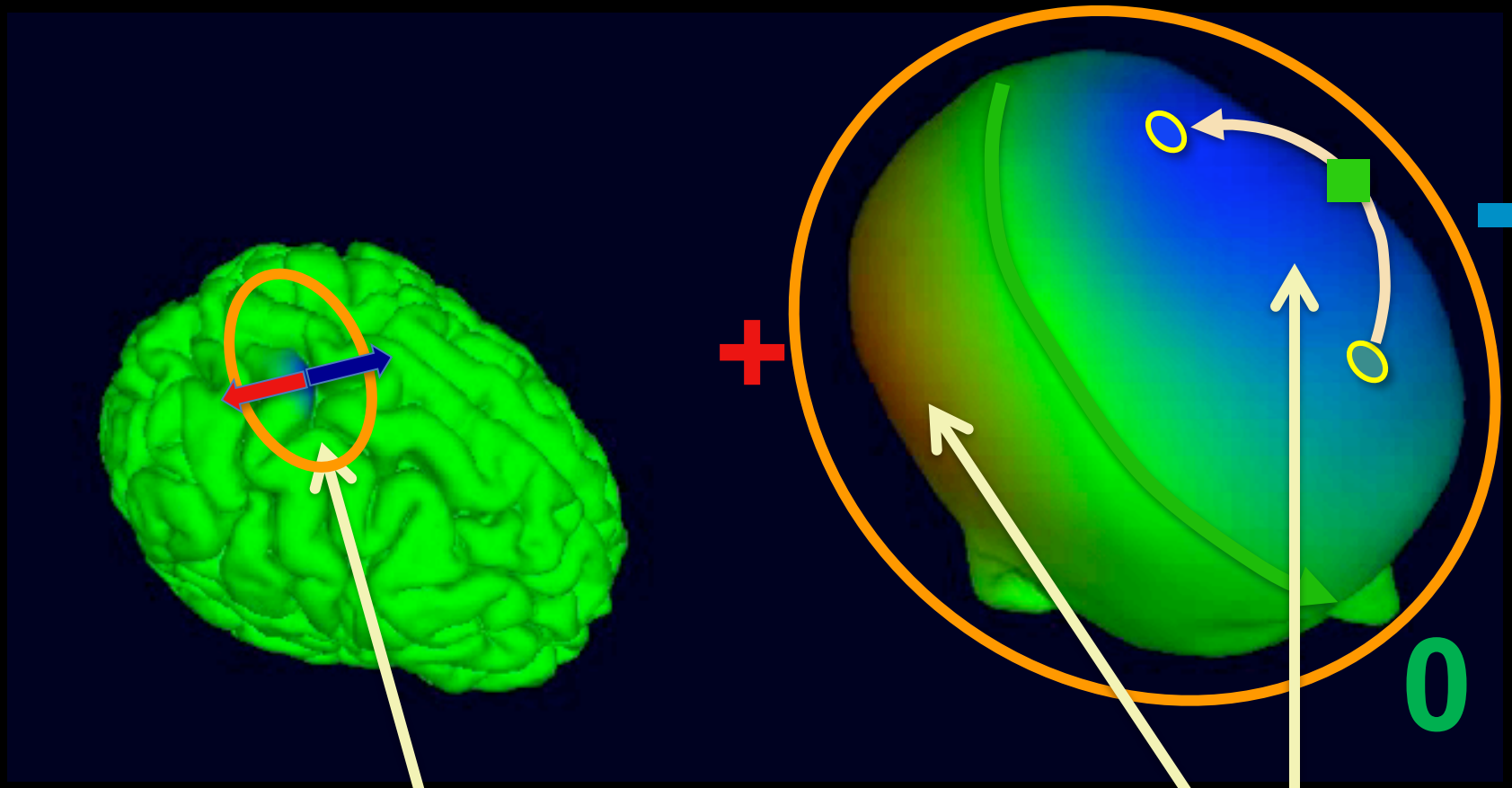
Cortical source current volume conduction patterns



Each scalp EEG data channel sums the projected activities of multiple brain (and non-brain) source processes.

S. Makeig 2007

The very broad EEG point-spread function

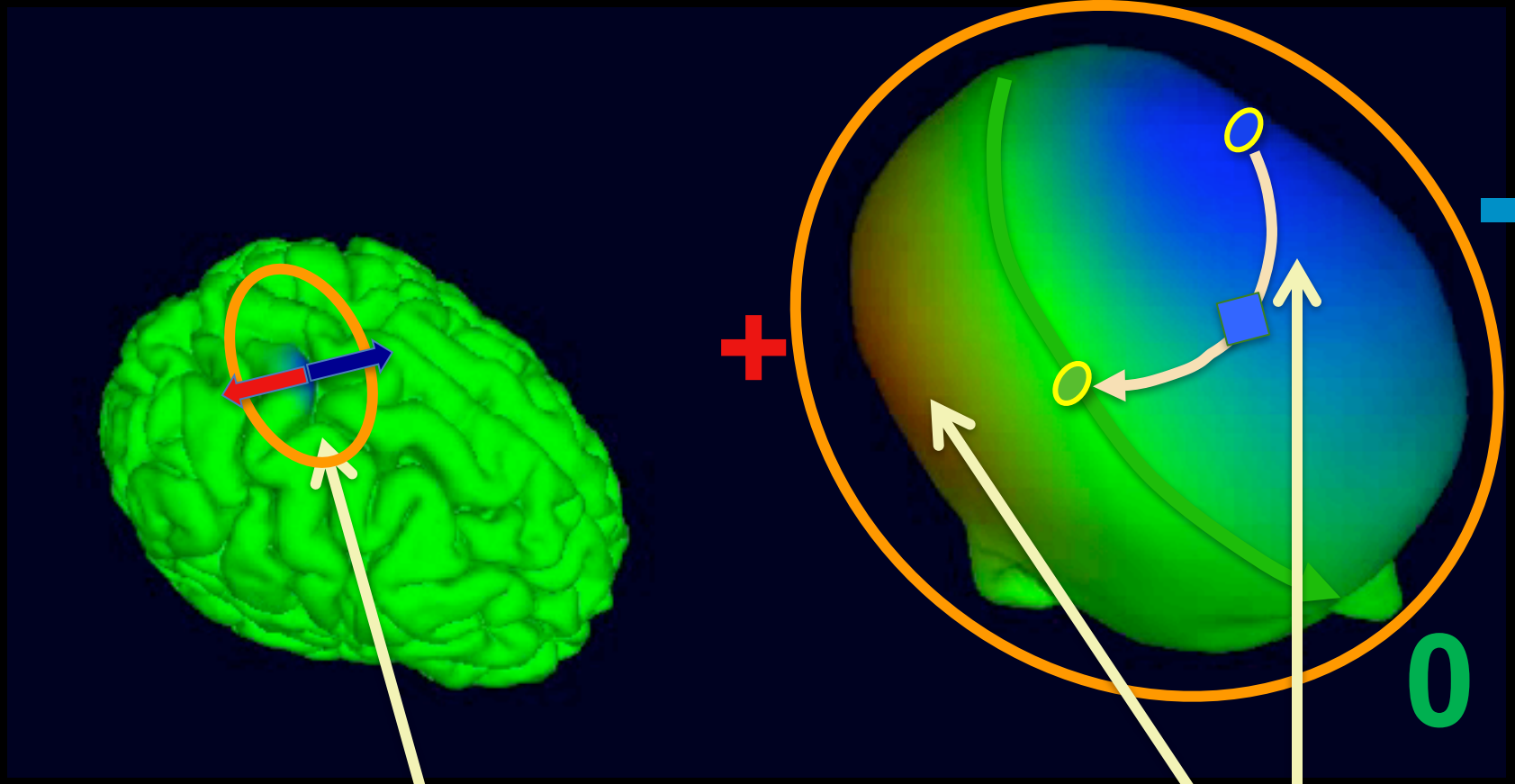


Single simulated parietal source →

Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The very broad EEG point-spread function

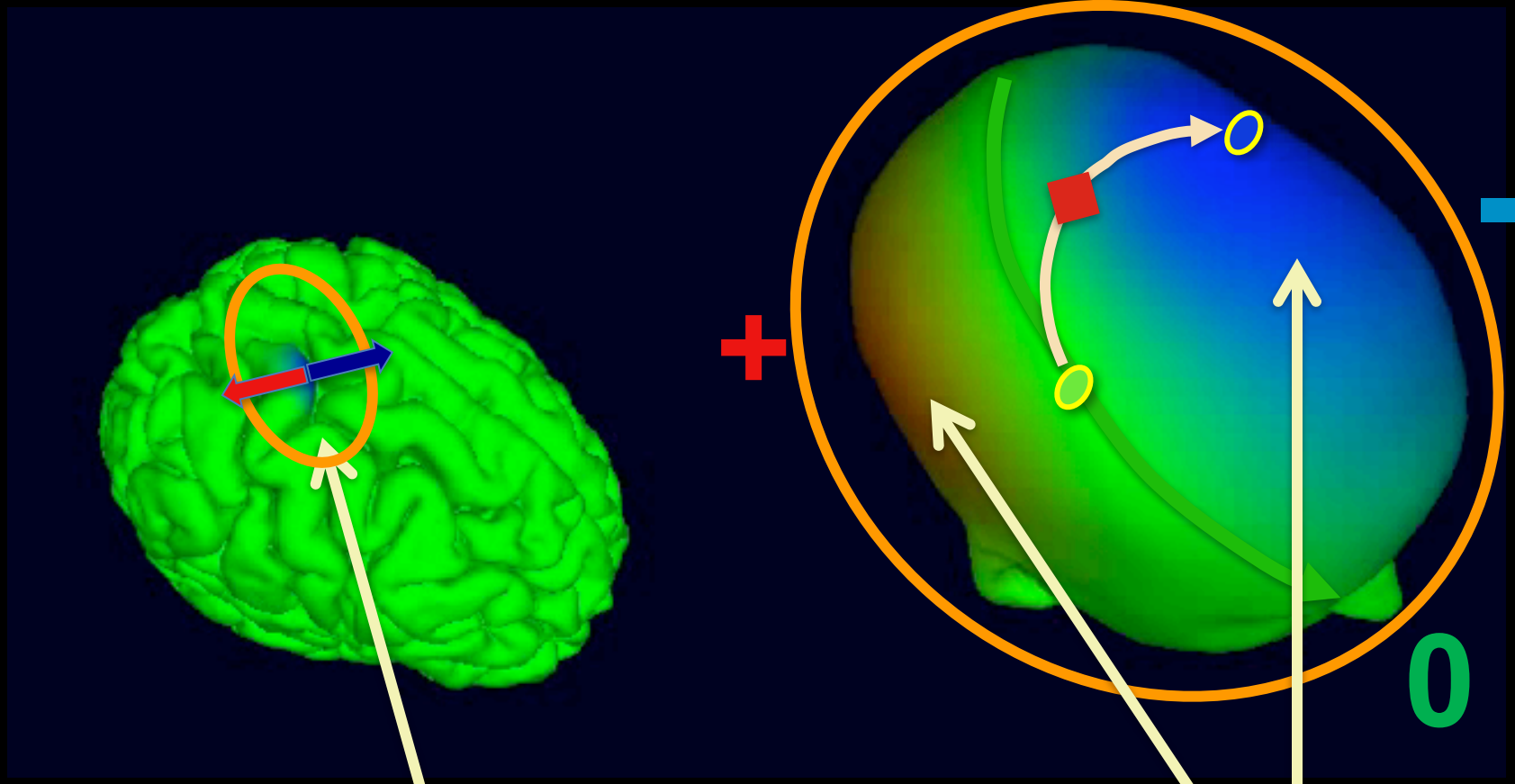


Single simulated parietal source →

Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The very broad EEG point-spread function

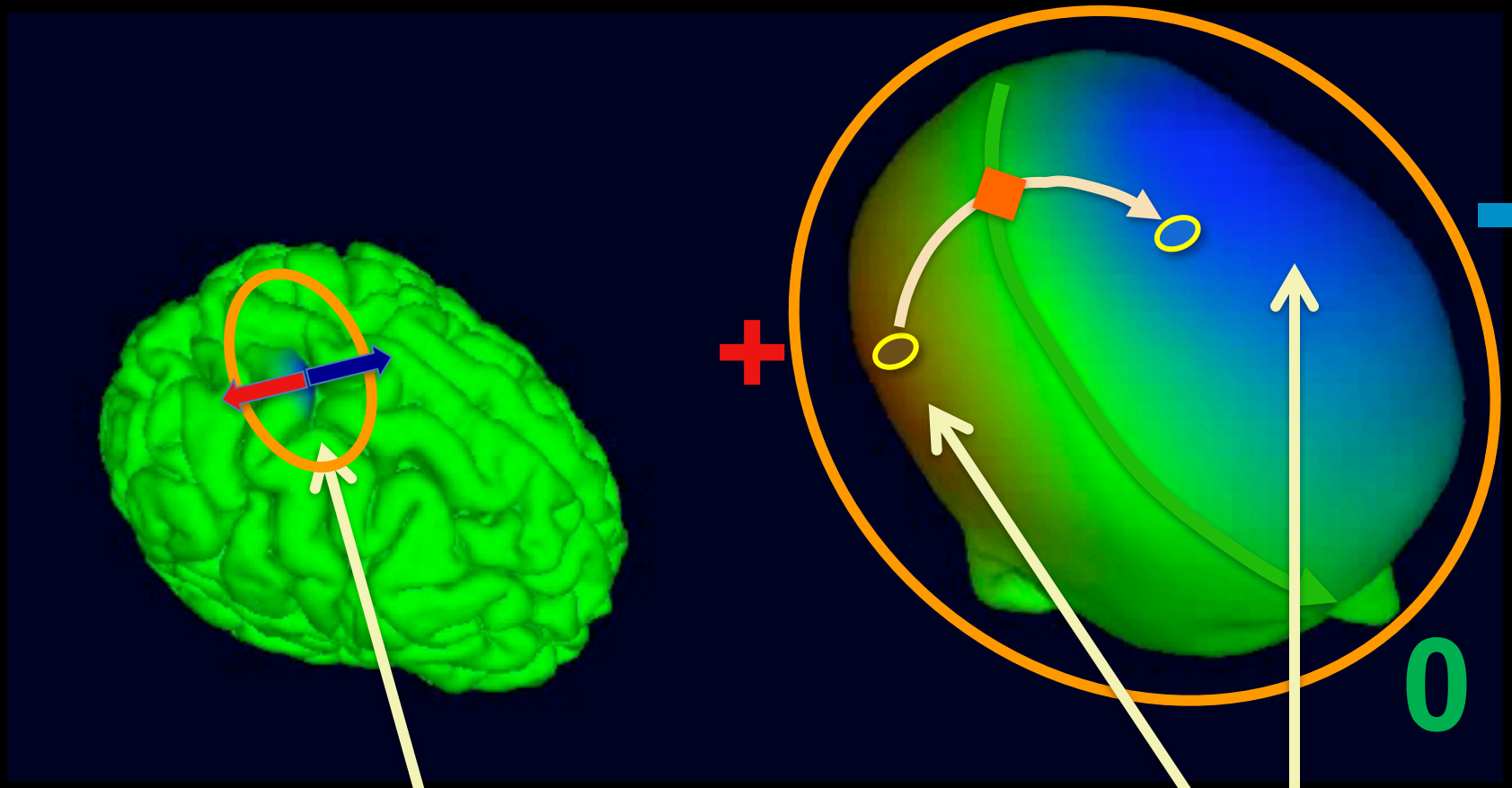


Single simulated parietal source →

Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The very broad EEG point-spread function

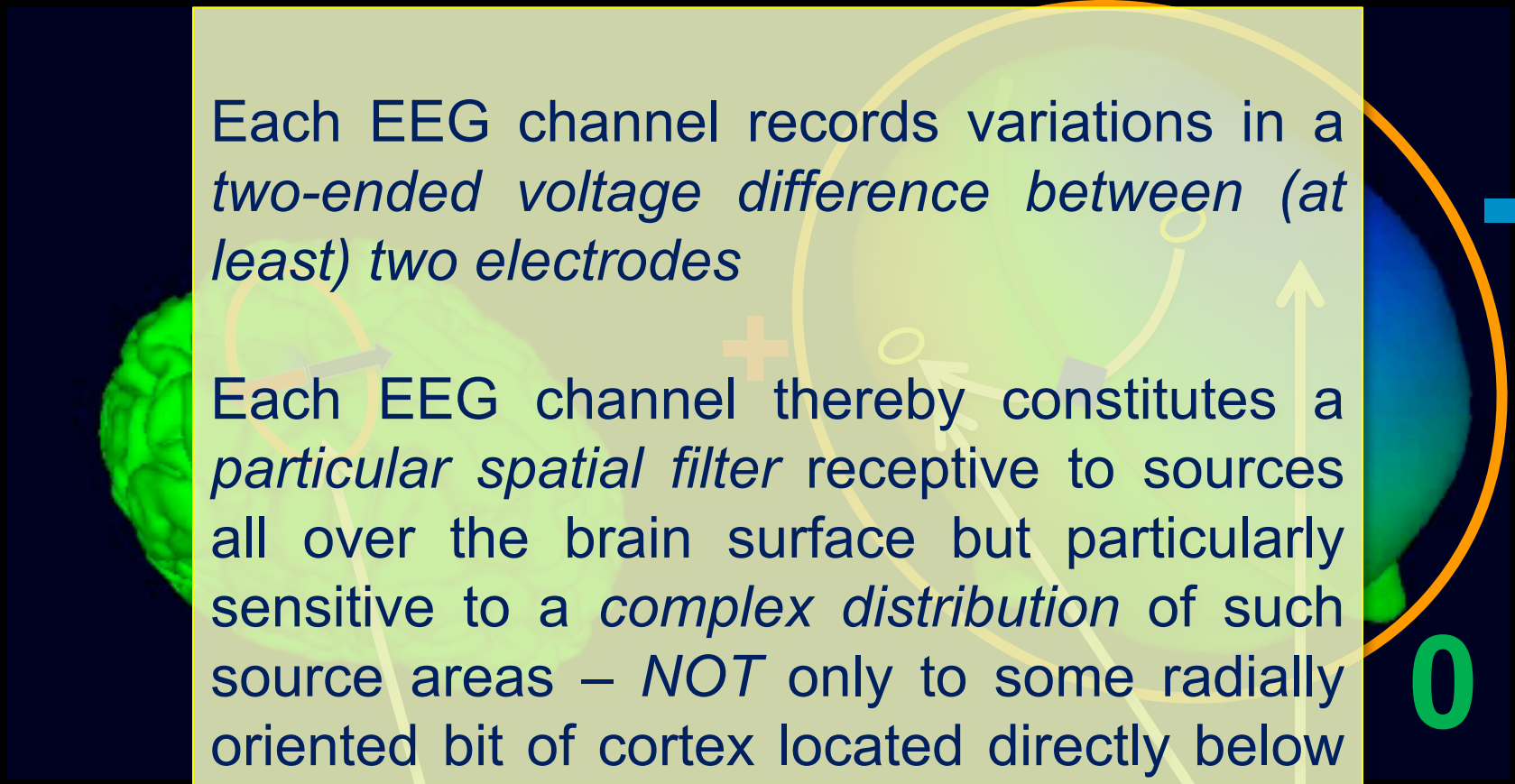


Single simulated parietal source →

Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The very broad EEG point-spread function



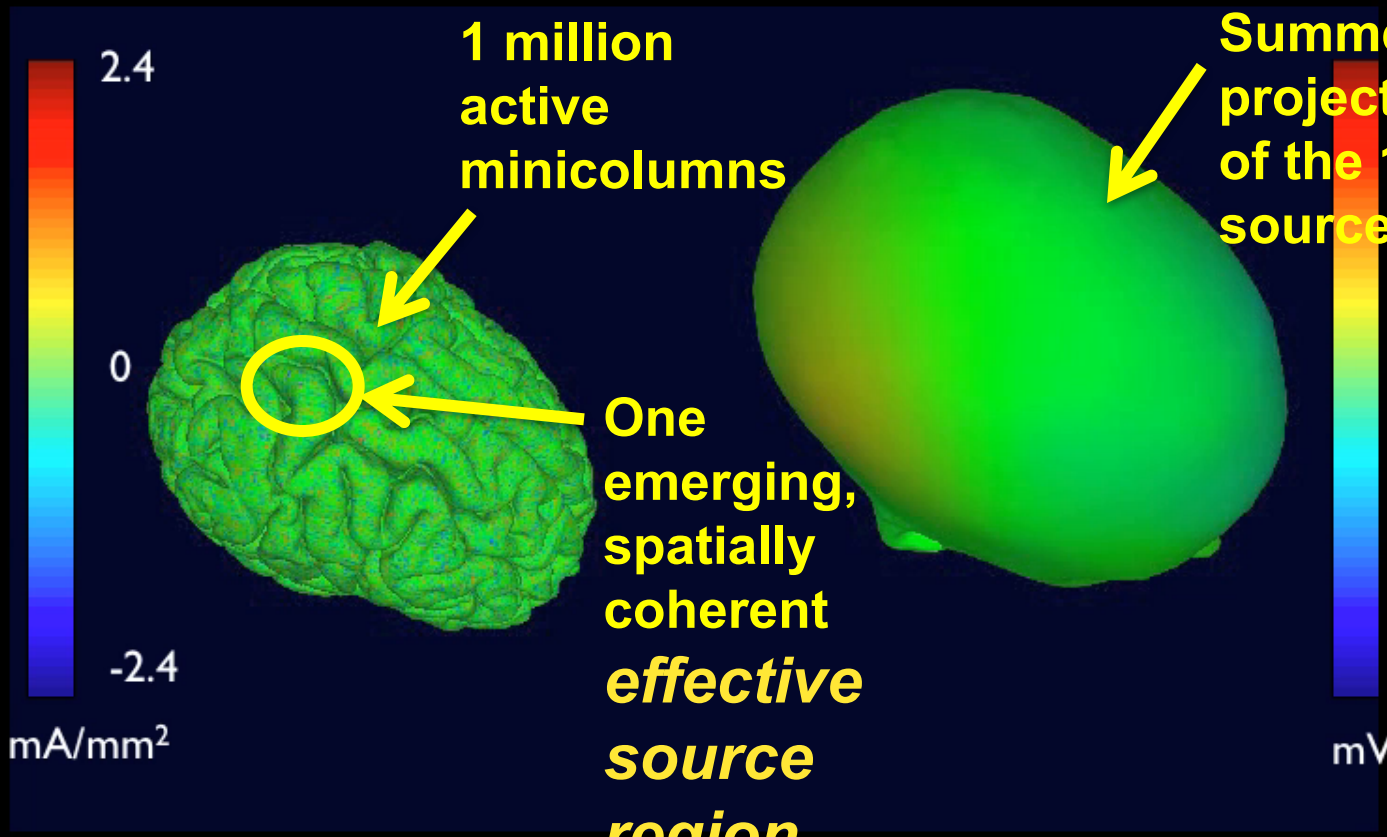
Each EEG channel records variations in a *two-ended voltage difference between (at least) two electrodes*

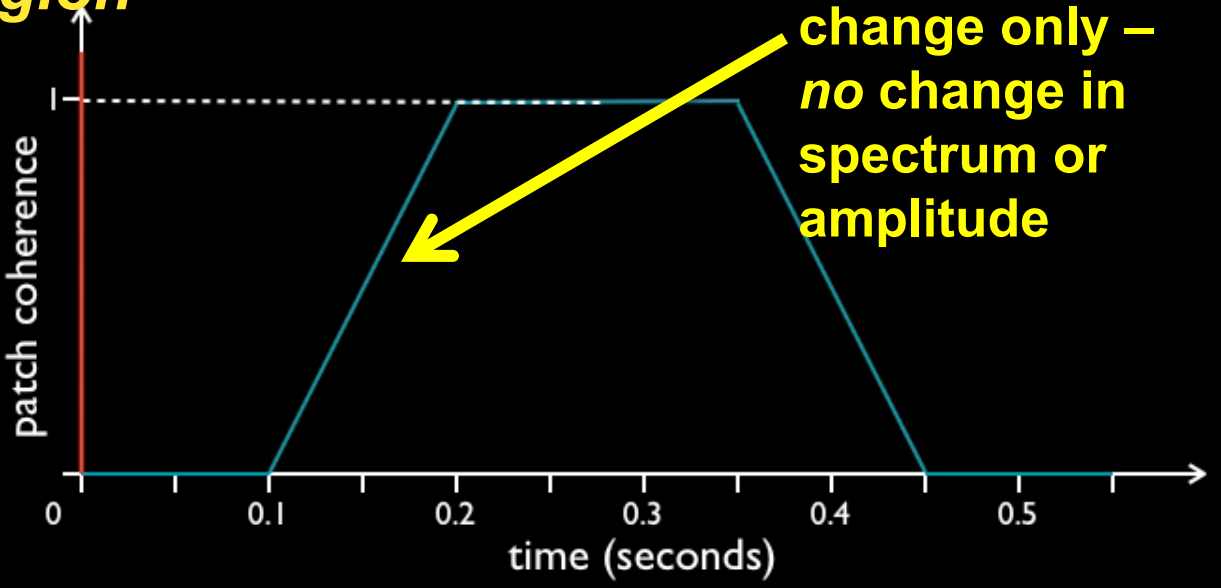
Each EEG channel thereby constitutes a *particular spatial filter* receptive to sources all over the brain surface but particularly sensitive to a *complex distribution* of such source areas – *NOT* only to some radially oriented bit of cortex located directly below *one* of the two channel electrodes!

Single simulated parietal source →

Very broad projected scalp potentials

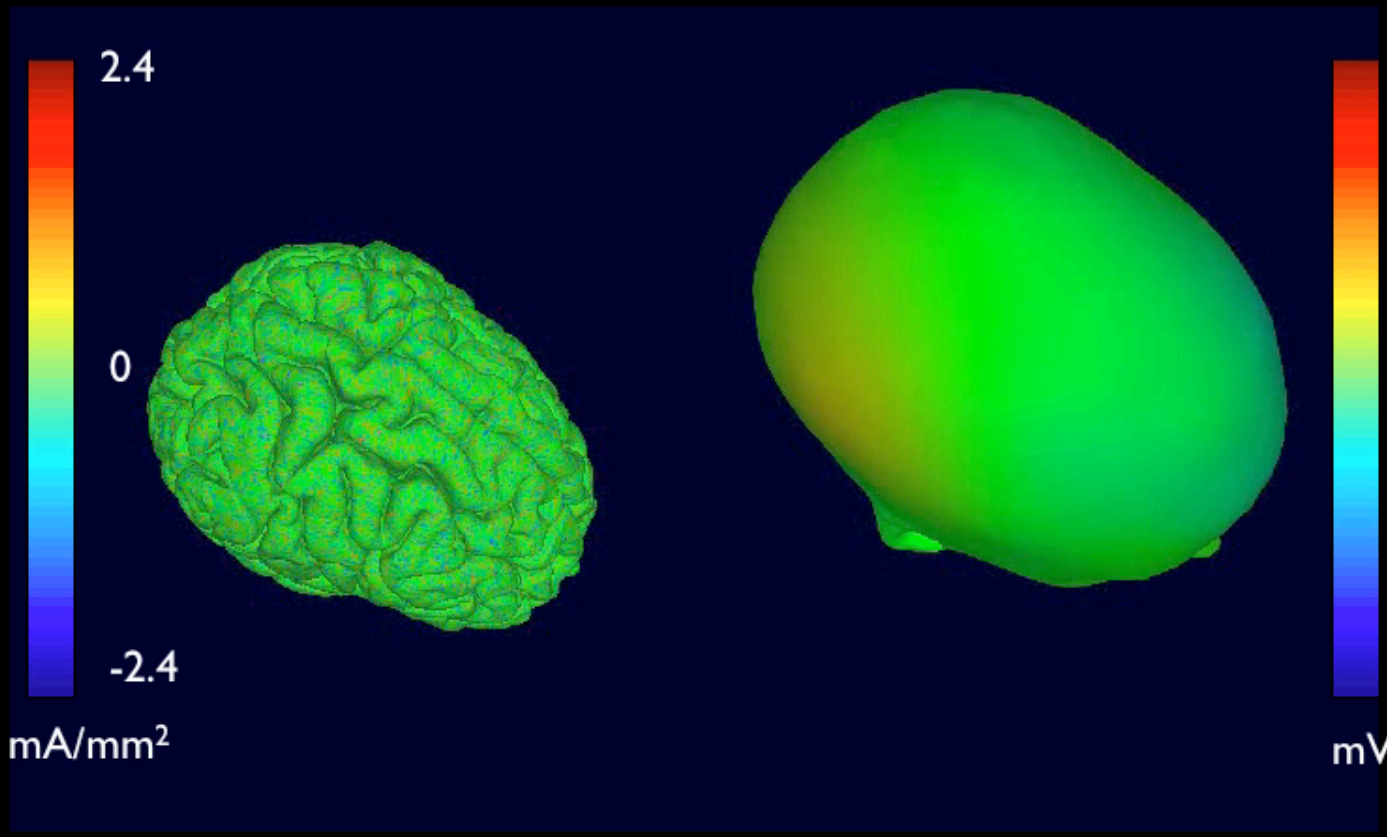
Akalin Acar & Makeig 2010

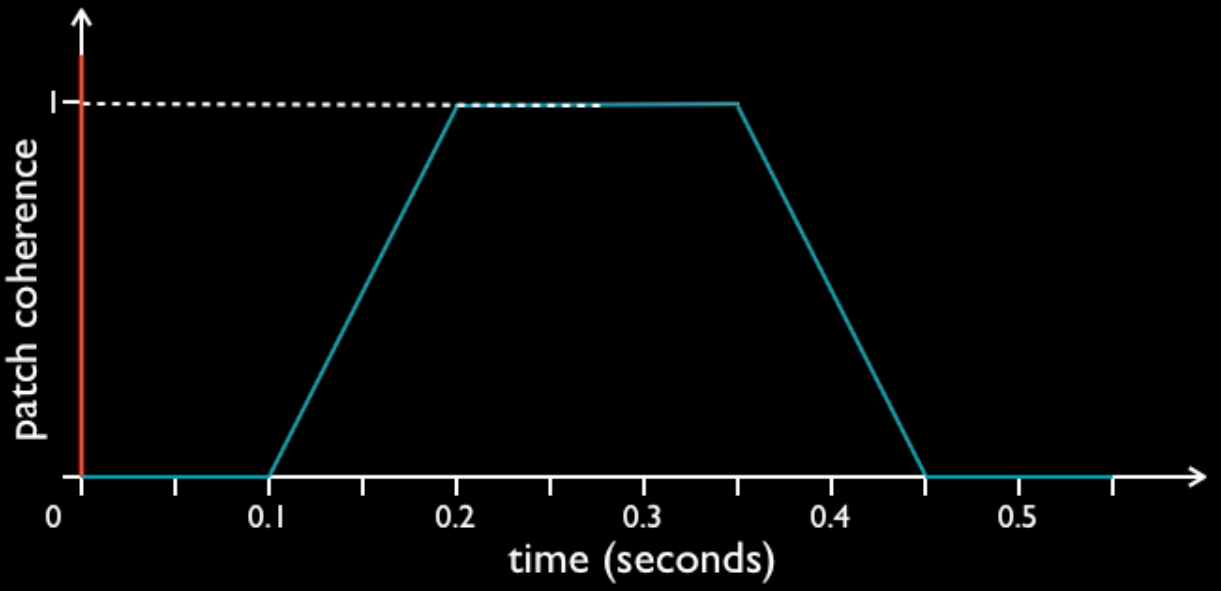




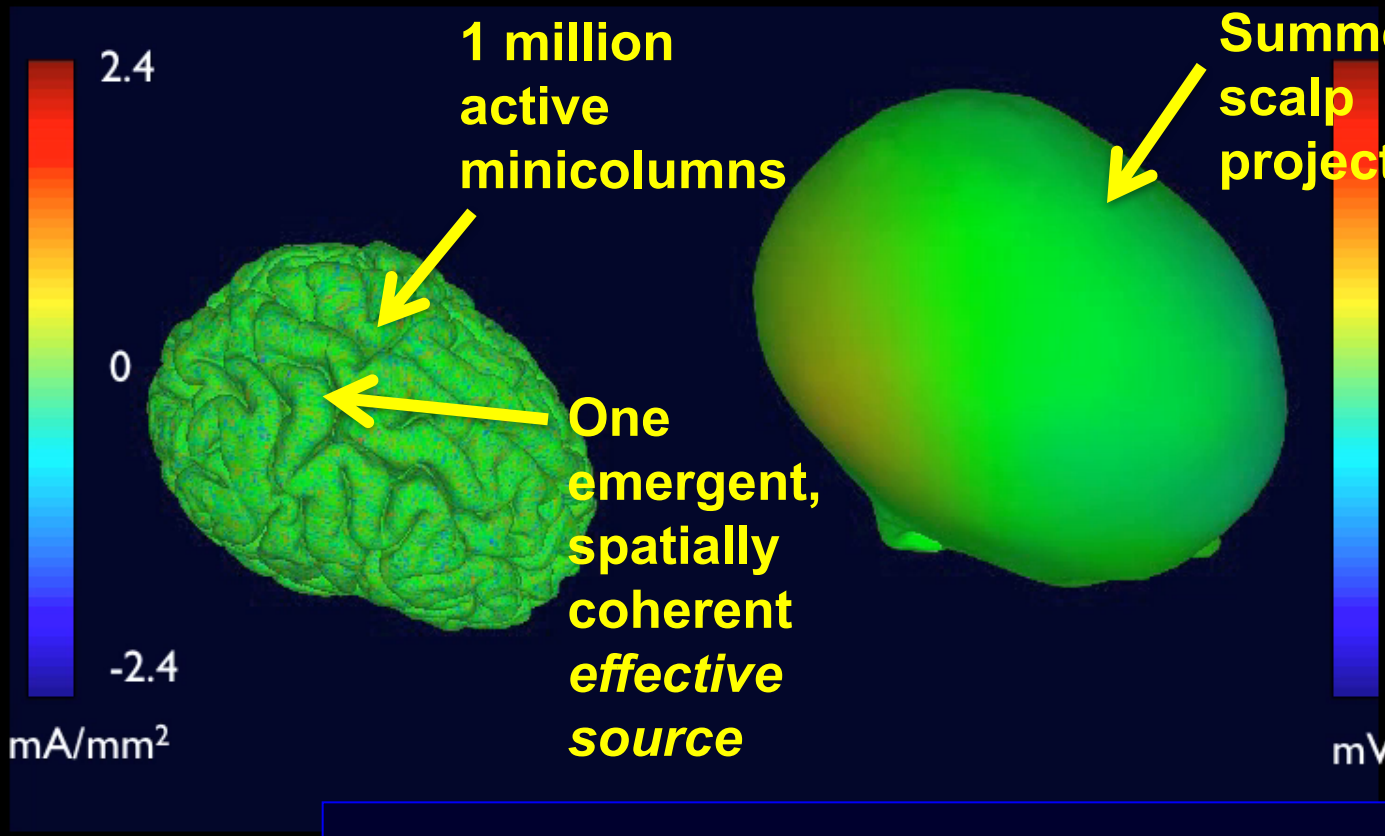
Local coherence change only – *no* change in spectrum or amplitude

Z. Akalin Acar & S. Makeig (2015)

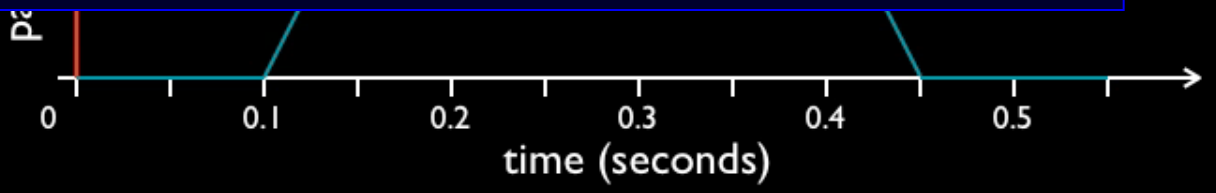




Z. Akalin Acar & S. Makeig (2015)

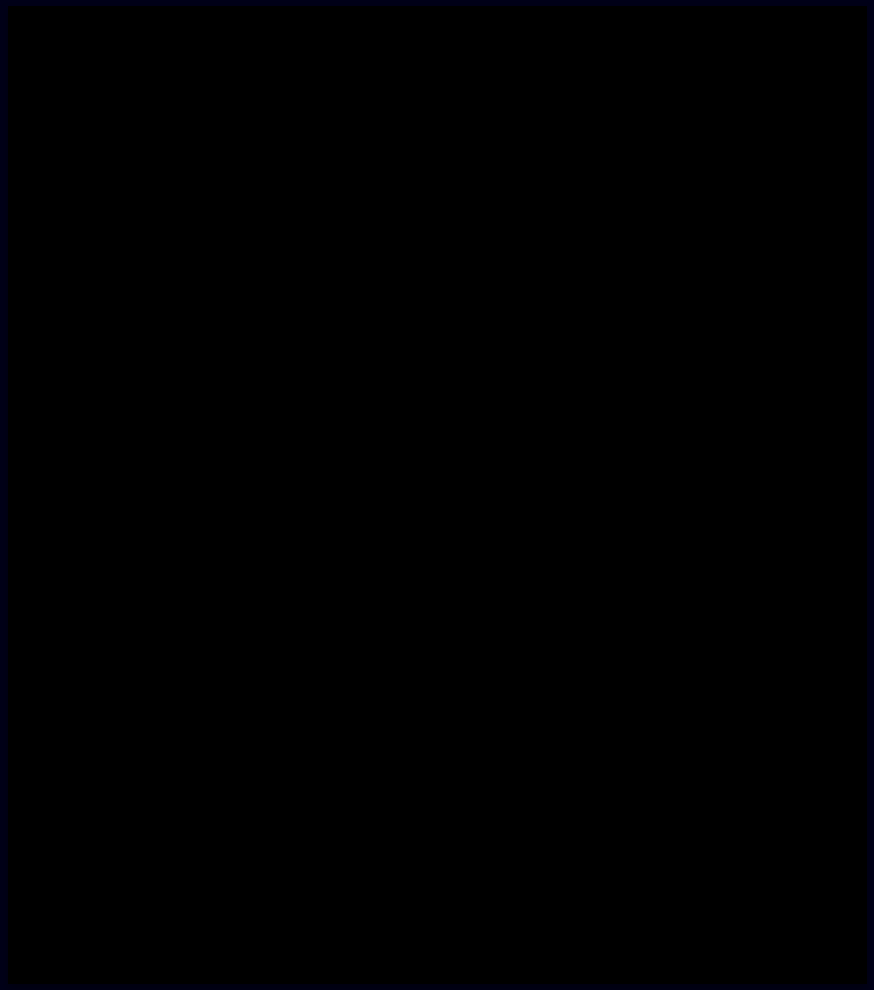


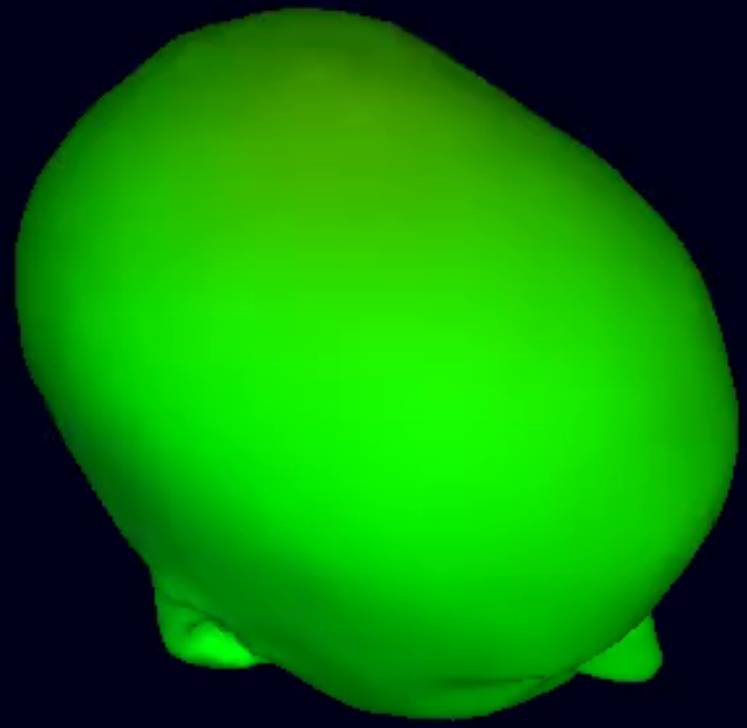
The *effective sources* of the scalp EEG are emergent islands of cortical LFP synchrony or near synchrony.



Z. Akalin Acar & S. Makeig (2015)

Scalp epiphenomena !



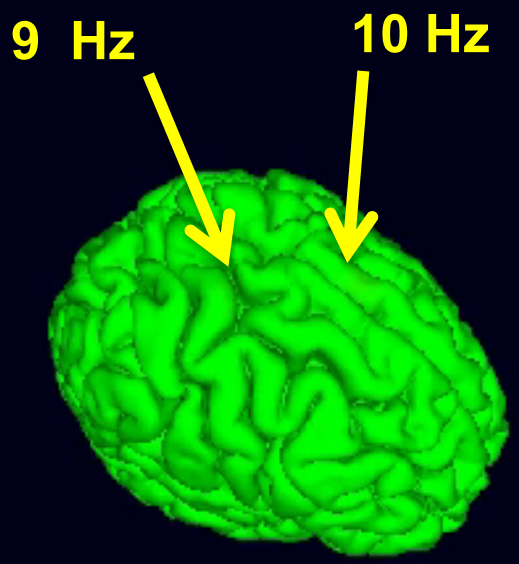


Scalp projection

Z. Akalin Acar & S. Makeig (2012)

Scalp epiphenomena !

Phenomena



Two spatially stationary cortical effective sources

Epiphenomenal

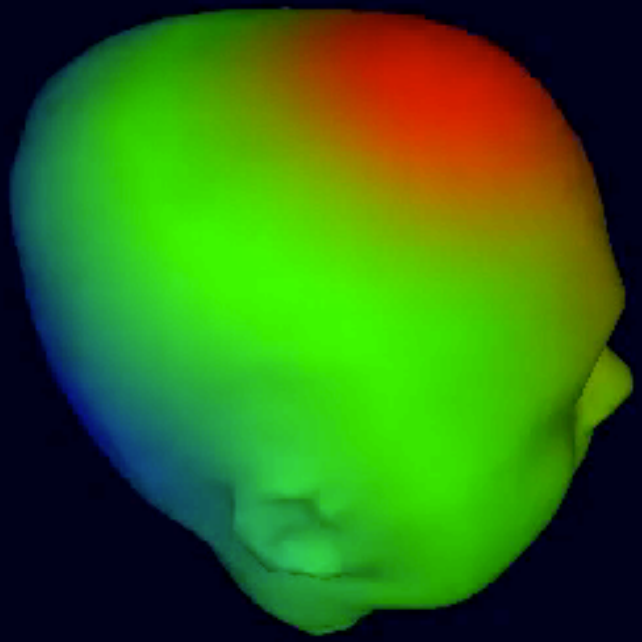
epiphenomena --

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

Summed scalp projection

Z. Akalin Acar & S. Makeig (2012)

Summed scalp projections of 13 effective brain sources



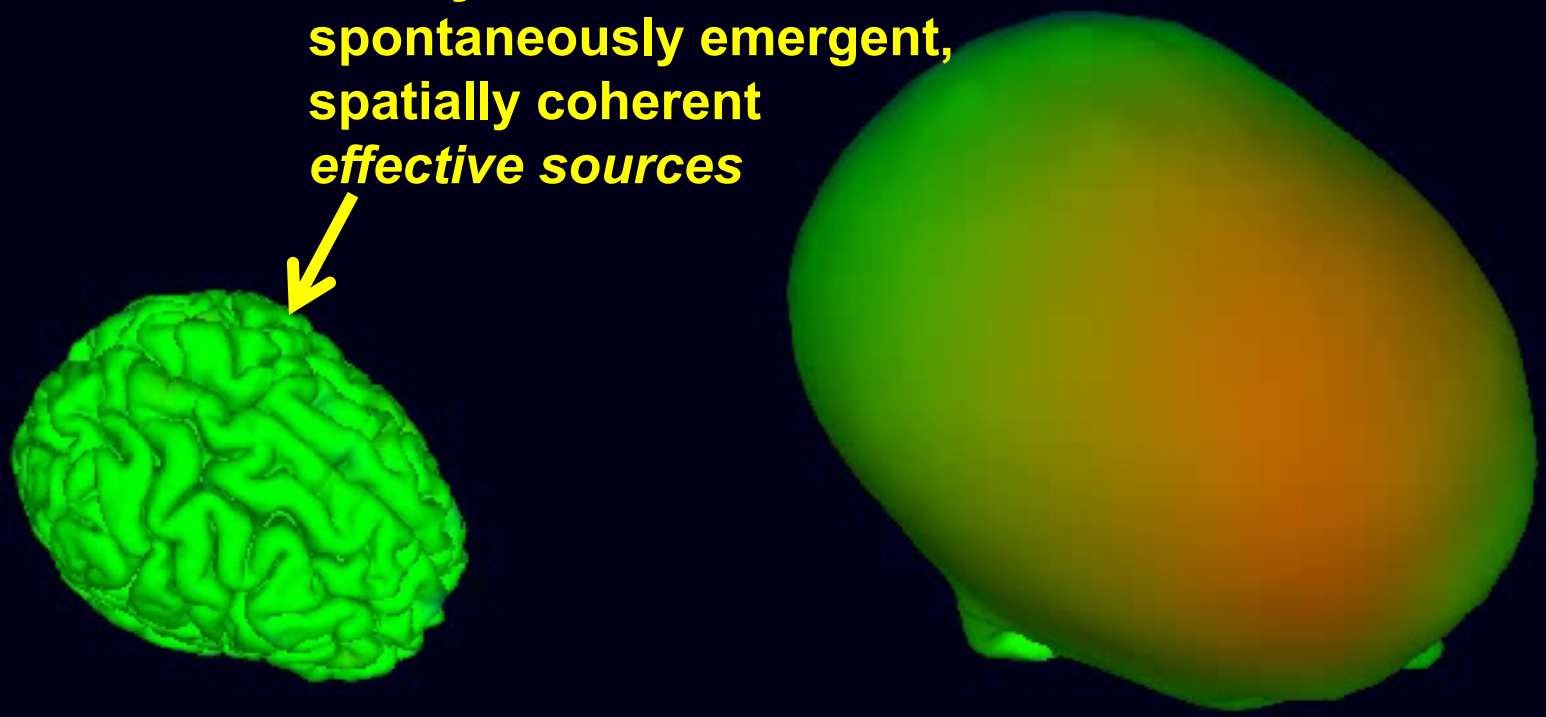
Epiphenomenal Impressions

Causal Phenomena

Z. Akalin Acar & S. Makeig (2016)

Summed scalp projections of 30 effective brain sources

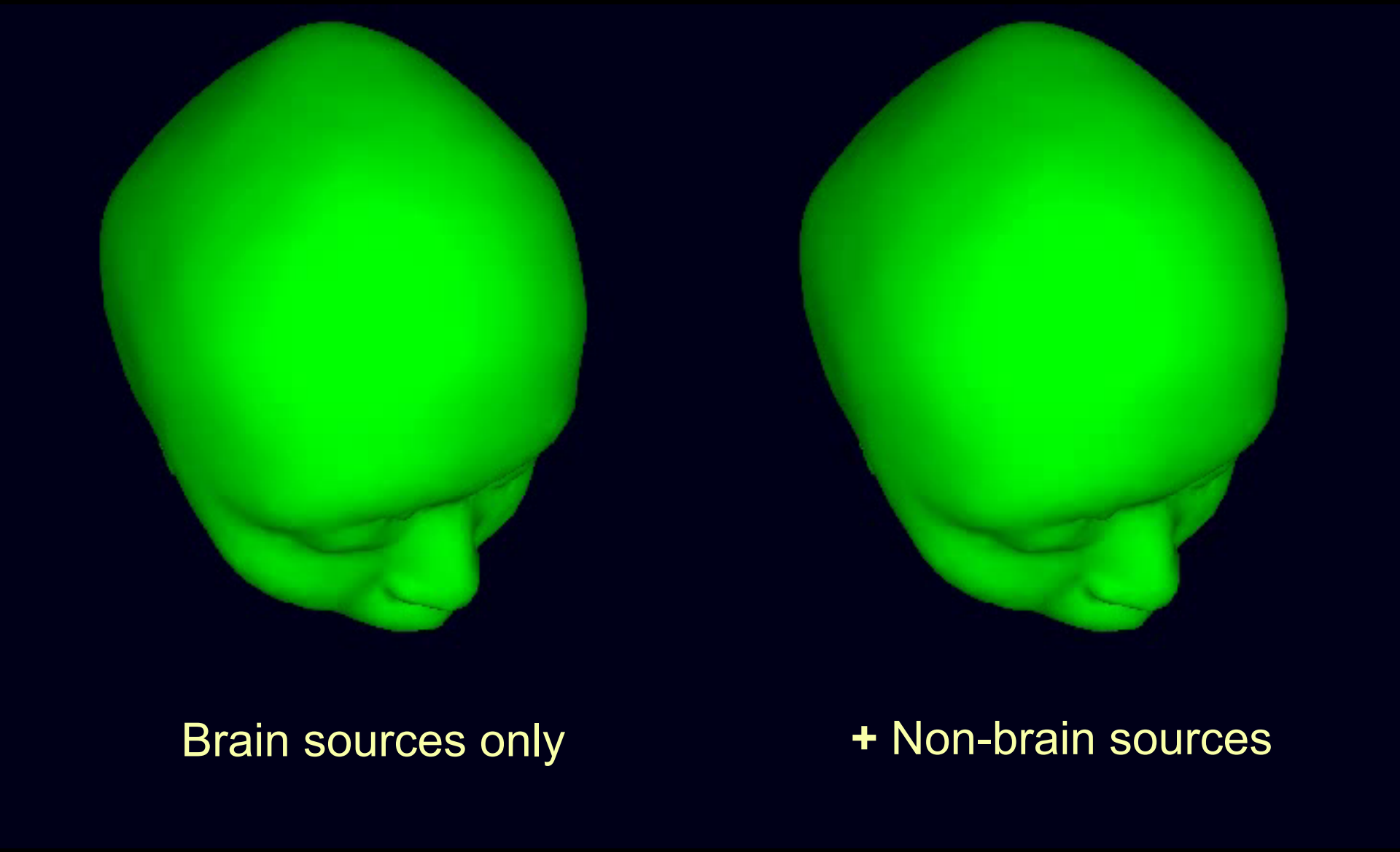
Thirty
spontaneously emergent,
spatially coherent
effective sources



Simulated EEG summing 30 cortical effective sources (animation at 1/5th real time)

Akalin Acar & Makeig 2010

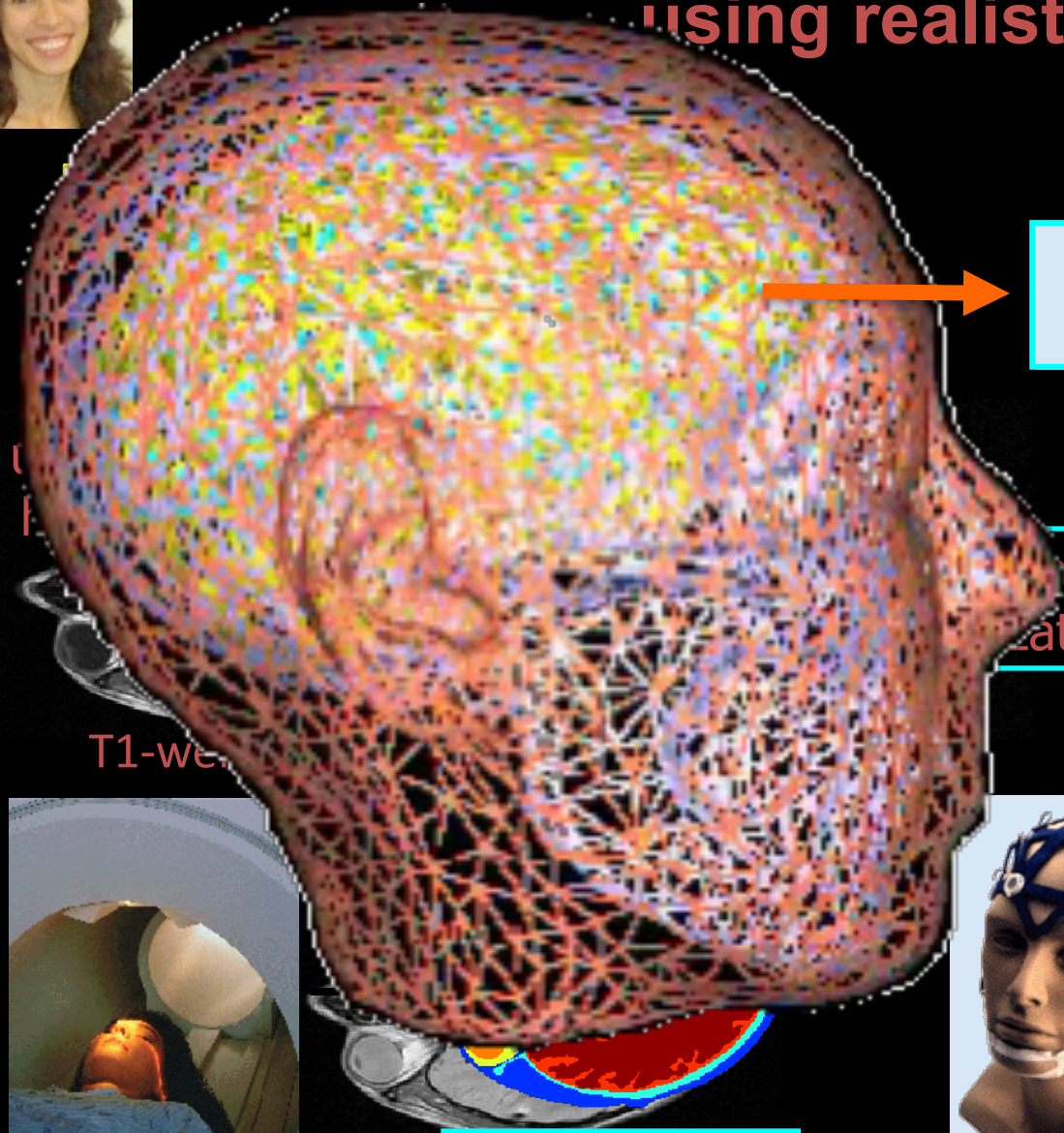
Non-brain source contributions to actual scalp EEG



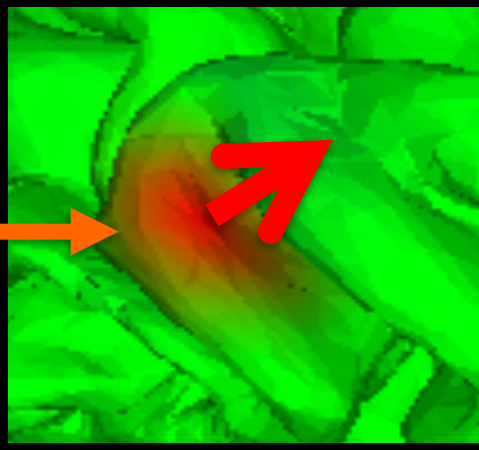
Brain sources only

+ Non-brain sources

Electromagnetic source localization using realistic head models



Simple Map



Source Estimate

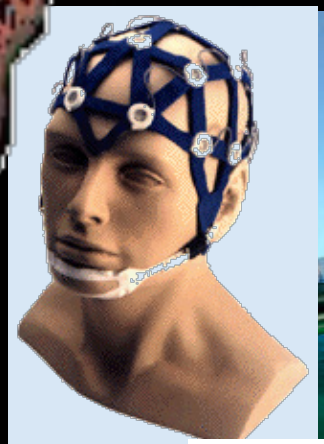
Signal Processing

T1-we

MRI

Proto Density

Segmentation

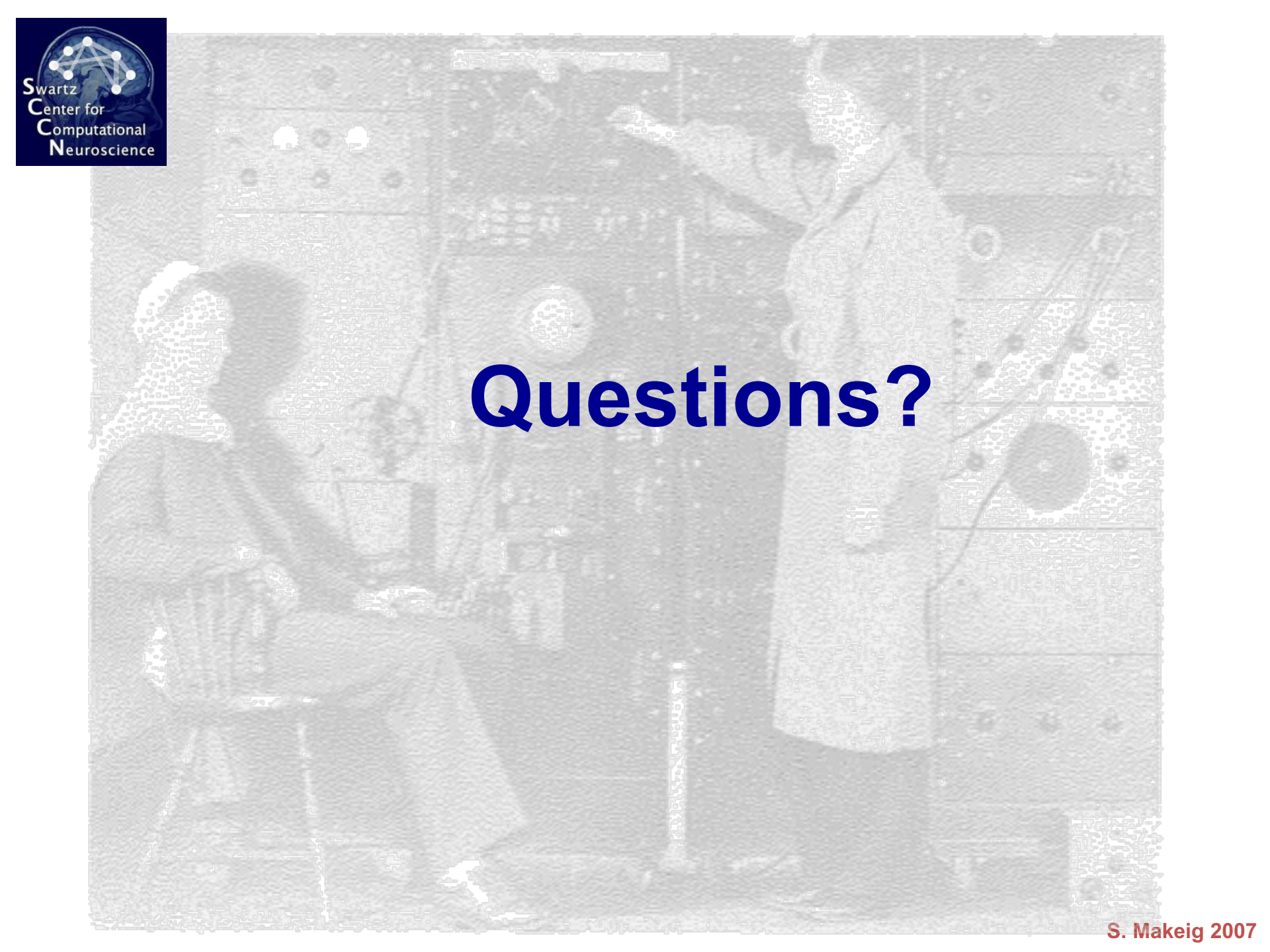


EEG/MEG

Zeynep Akalin Acar & Scott Makeig ‘06

Cloud art: Berndnaut Smilde

S. Makeig, 2016

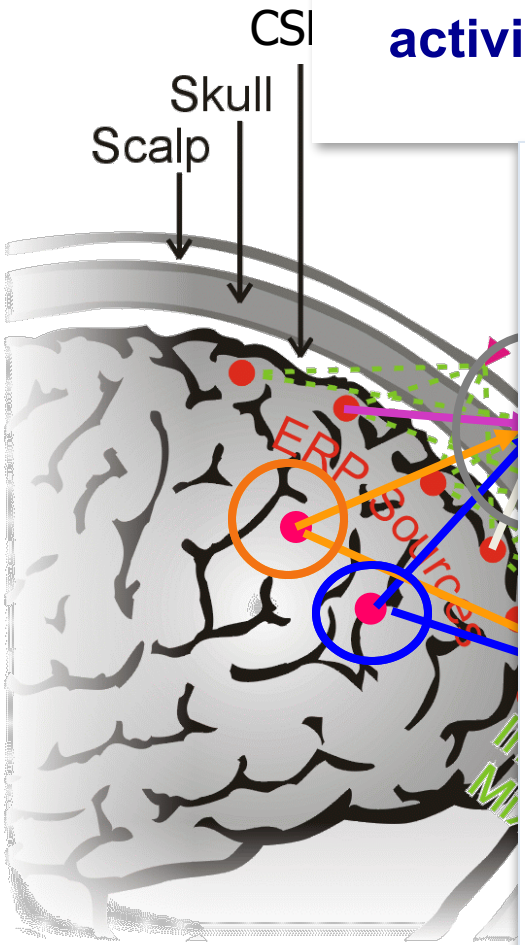


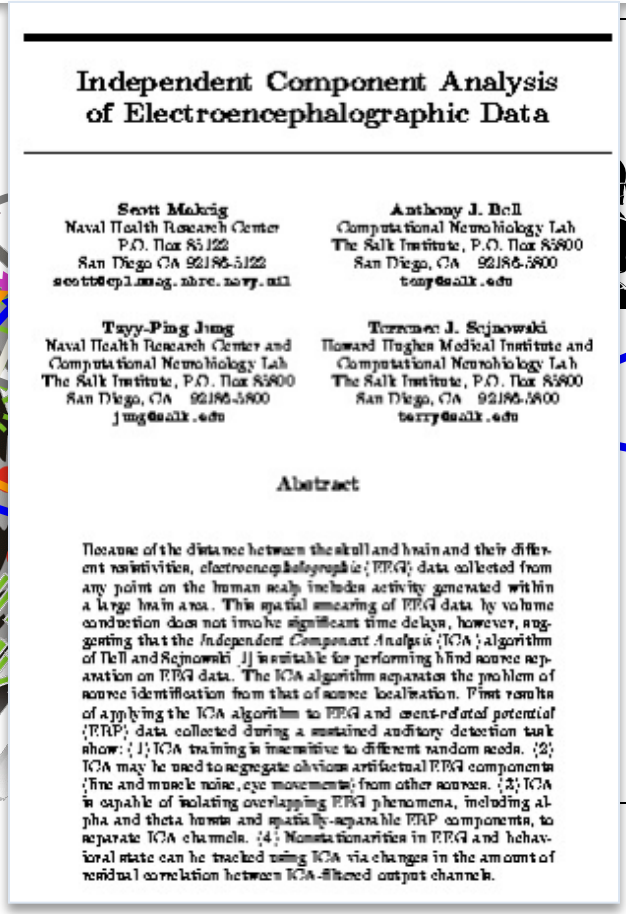
Questions?

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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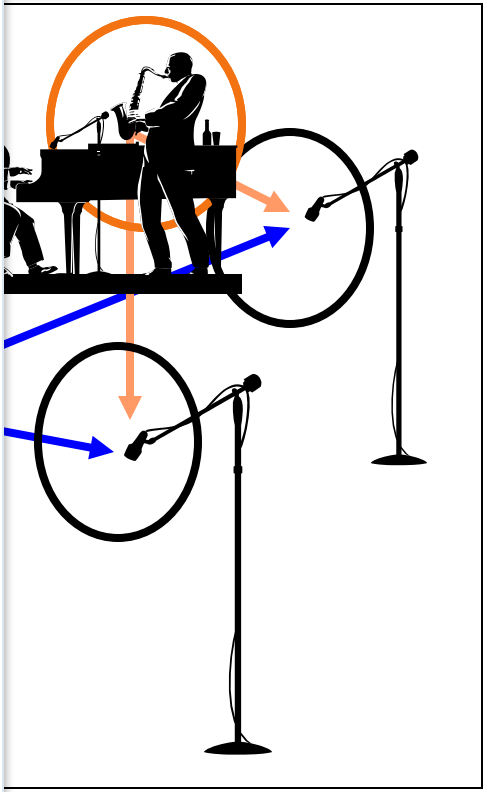
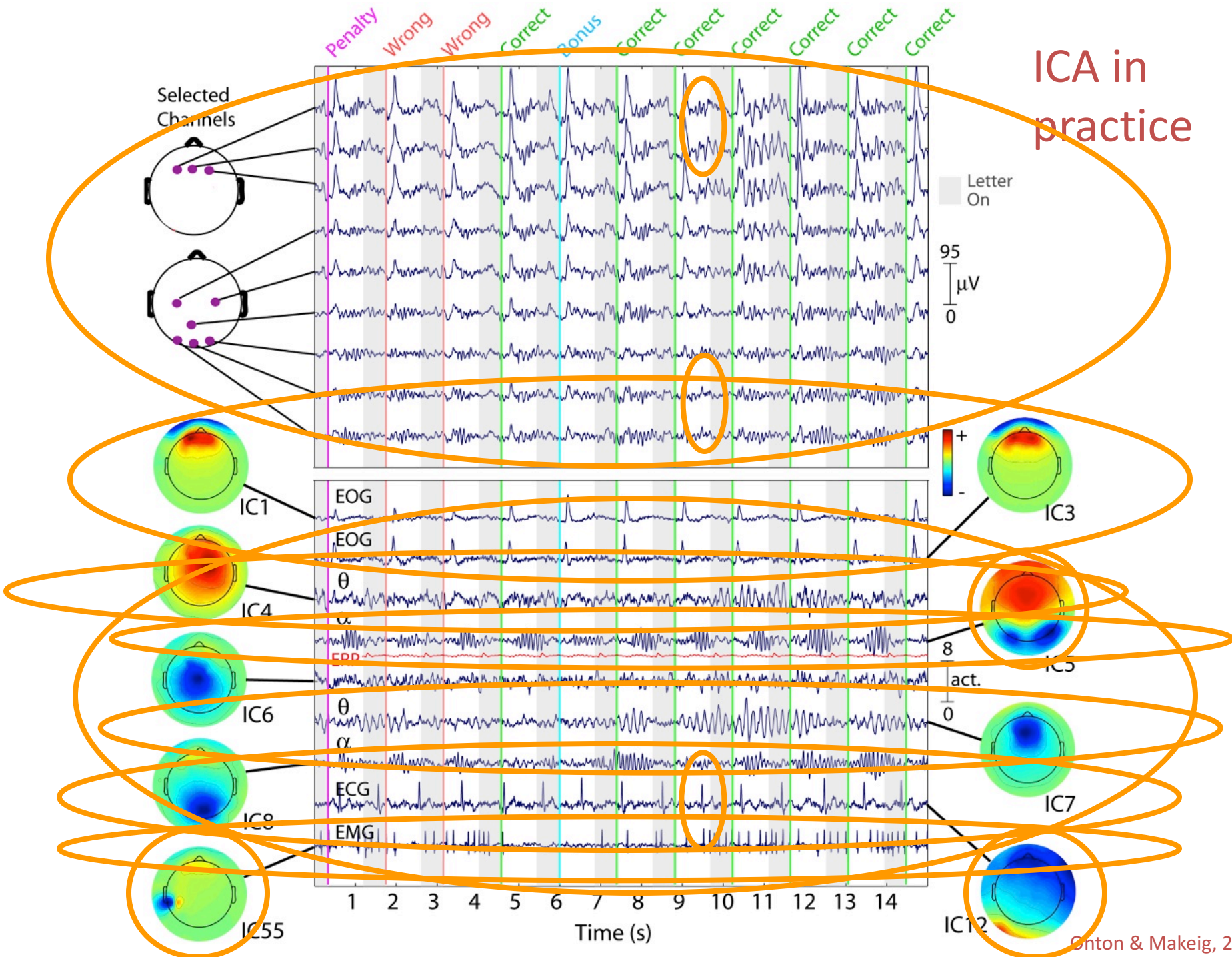
Abstract

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.

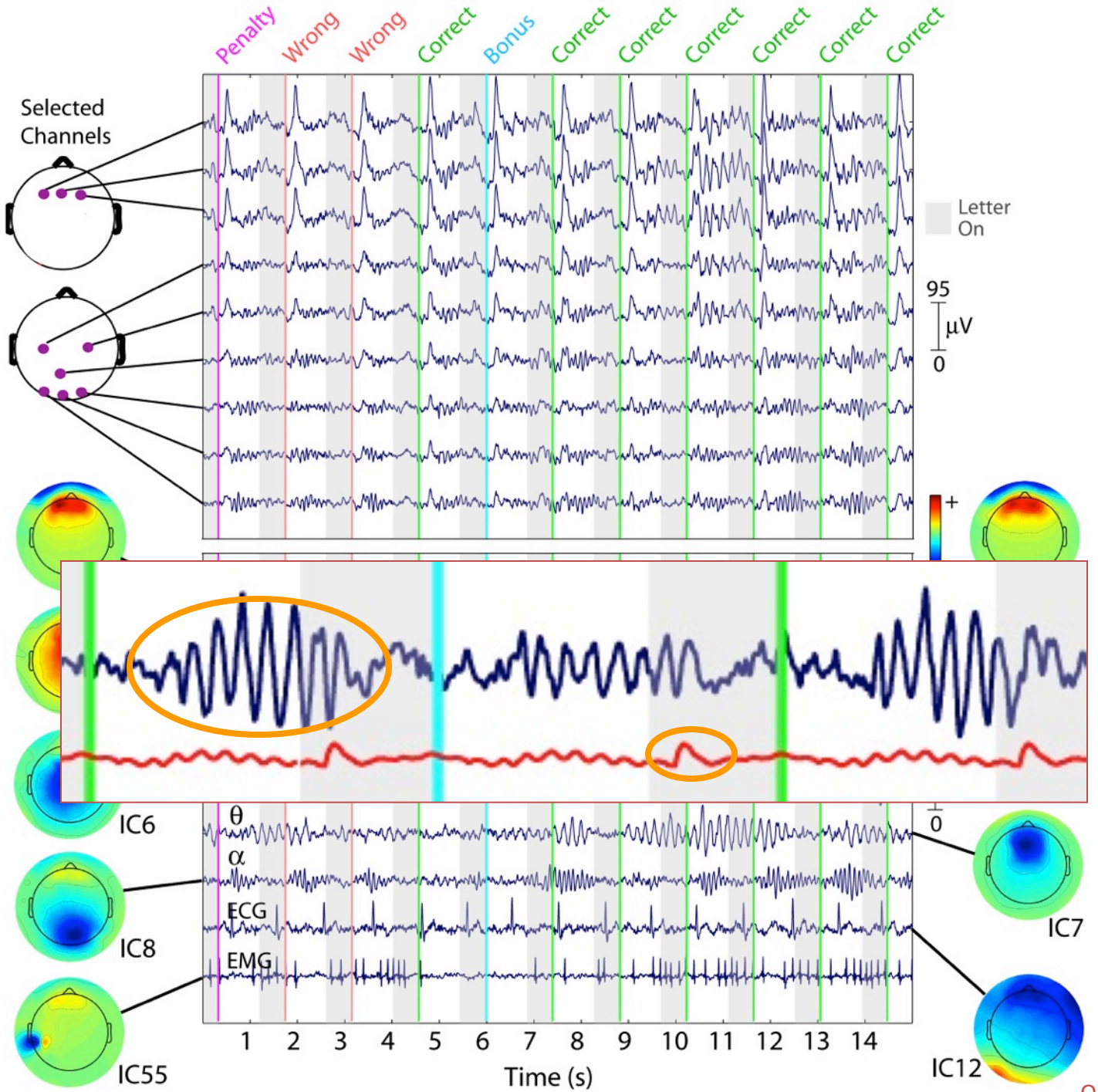


S. Makeig, S. Enghoff (2000)

ICA in practice

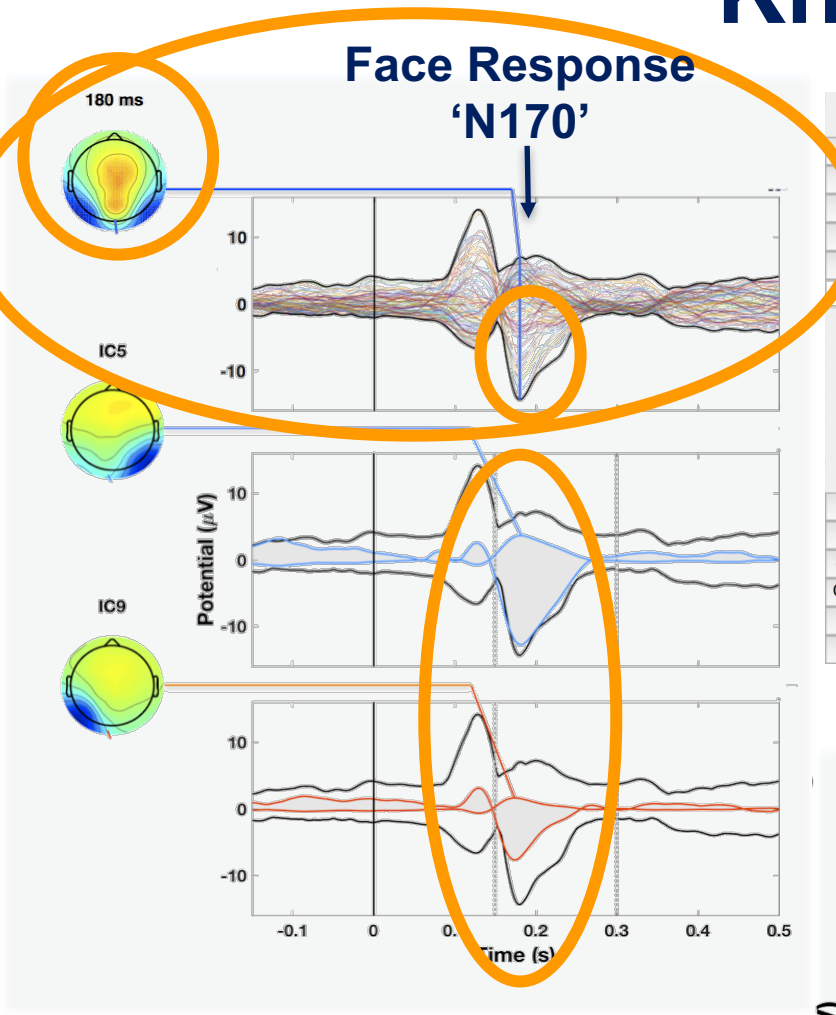


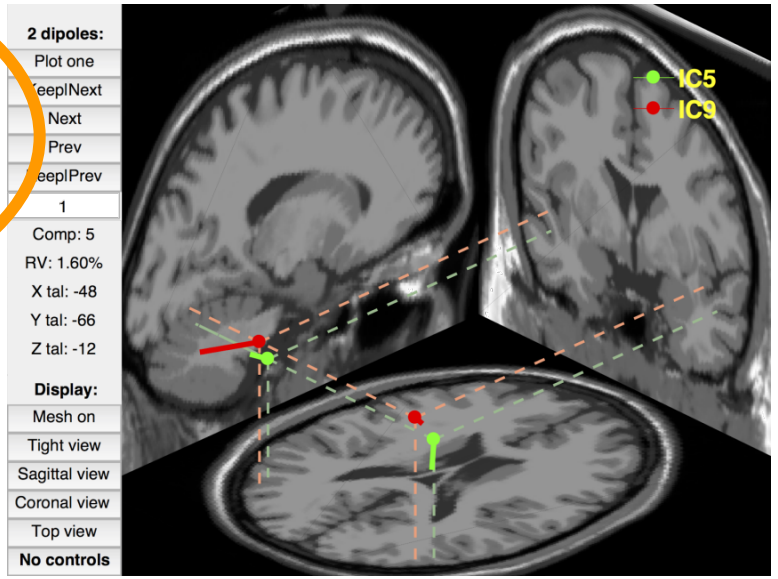
Onton & Makeig, 2006

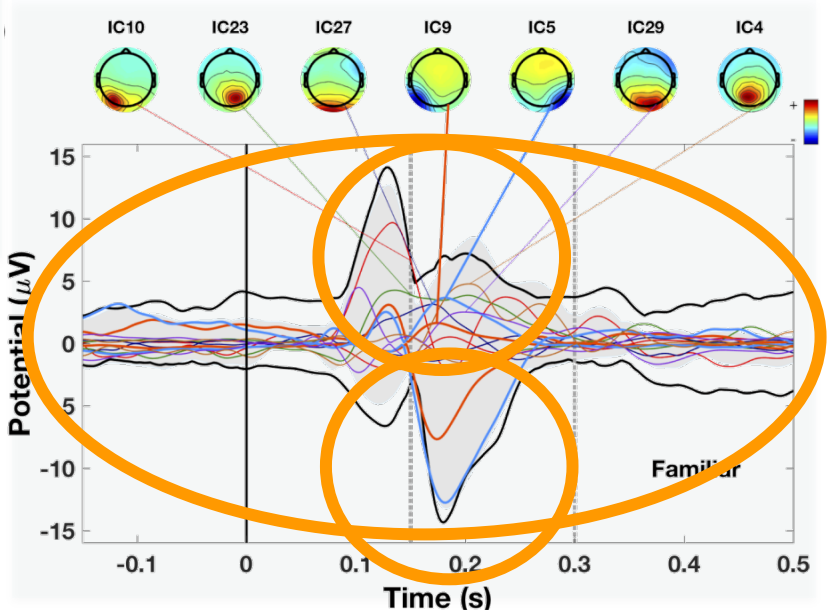


Onton, Makeig (2006)

Knowing

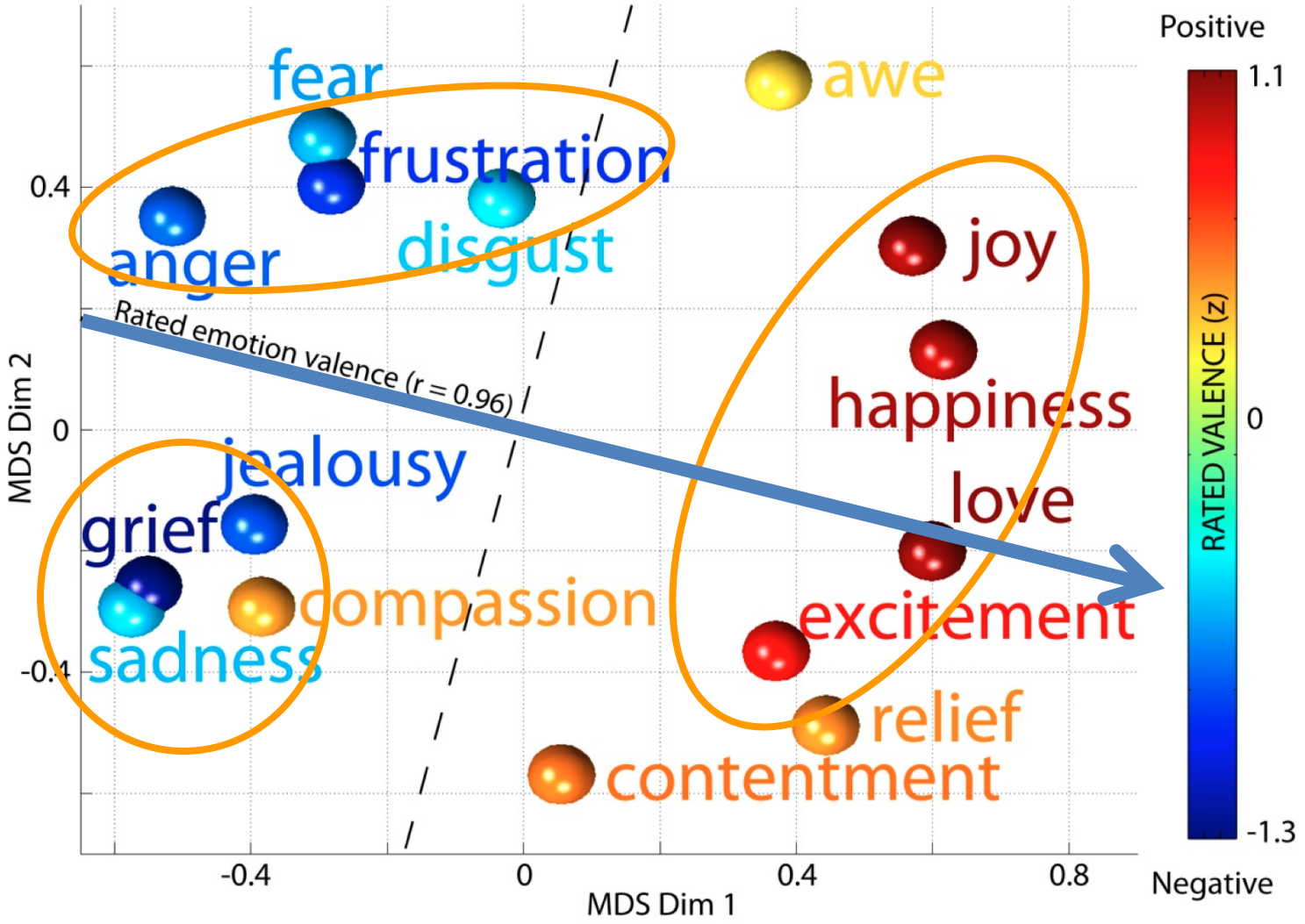






S. Makeig (2017)

Feeling



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

Willing

Imaging Human Agency

Mobile Brain/Body Imaging (MoBI)

S . Makeig, 2007