Mining Cognitive Brain Dynamics I

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Institute for Neural Computation
University of California San Diego

12th EEGLAB Workshop @ UCSD

November, 2010

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 plots (Jung & Makeig)
- 2000 - Toolbox GUI design (Delorme)
- 2002 - EEGLAB (sccn.ucsd.edu)
- 2004 - NIH support, and (Delorme & Makeig) reference paper
- 2004 - 1st EEGLAB workshop (UCSD, La Jolla, California)
- 2004 - 1st EEGLAB plug-ins
- 2005 – Workshops in Porto (Portugal) and Libon (SPR)
- 2006 – Workshop in Singapore
- 2006 - 1st STUDY structure and component clustering tools
- 2007 - Workshops in Aspet (France), La Jolla (California), Santiago (Chile)
- 2008 - NIH support renewed…
- 2009 – NFT – Neuroelectromagnetic Forward Head Modeling Toolbox
- 2009 - Workshops in Bloomington Indiana, Aspet France, La Jolla California, Sydney Australia
- 2009 – ERICA DataRiver/Producer – Experimental Real-time Interactive Control & Analysis
- 2010 – Workshops in Jyvaskyla Finland, NCTU, Taiwan, Portland Oregon, and UCSD
- 2010 - HeadIT database tied to EEGLAB
- 2011 – EEGLAB Chat introduced

S. Makeig 2010

EEGLAB downloads for 20/06/2007

Total count is 34

Username	Email	Comments
Russia	@mail.ru	eeg, erp, bci
Company	@nexstim.com	EEG developer
Indonesia	@tf.itb.ac.id	Brain Computer Interface
Finland	@psyka.jyu.fi	
Australia	@newcastle.edu.au	Auditory Psychophysics Psychopathology
La Jolla	@gmail.com	Cogneuro EEGlab is great!
China	@126.com	hi!
?	@yahoo.com	LFP in DBS patients
US Gov	@pnl.gov	
US EDU	@pet.wpic.pitt.edu	EEG and ERP responses to music stimuli
US EDU	@wjh.harvard.edu	Neuroscience
US EDU	@vlu.edu	olfaction ERP
Switzerland	@student.ethz.ch	
Sweden	@neuro.gu.se	EEG
Germany	@med.uni-muenchen.de	
China?	@163.com	Signal Processing
China	@sina.com	ica
Finland	@helsinki.fi	cognitive brain research
Spain	@ugr.es	
Netherlands	@sdf.nl	dfg
Company?	@tom.com	BCI
?	painfulresult@.com	
France	@hotmail.fr	Biomedical engineering movement-related cortical potentials brain-computer interfaces

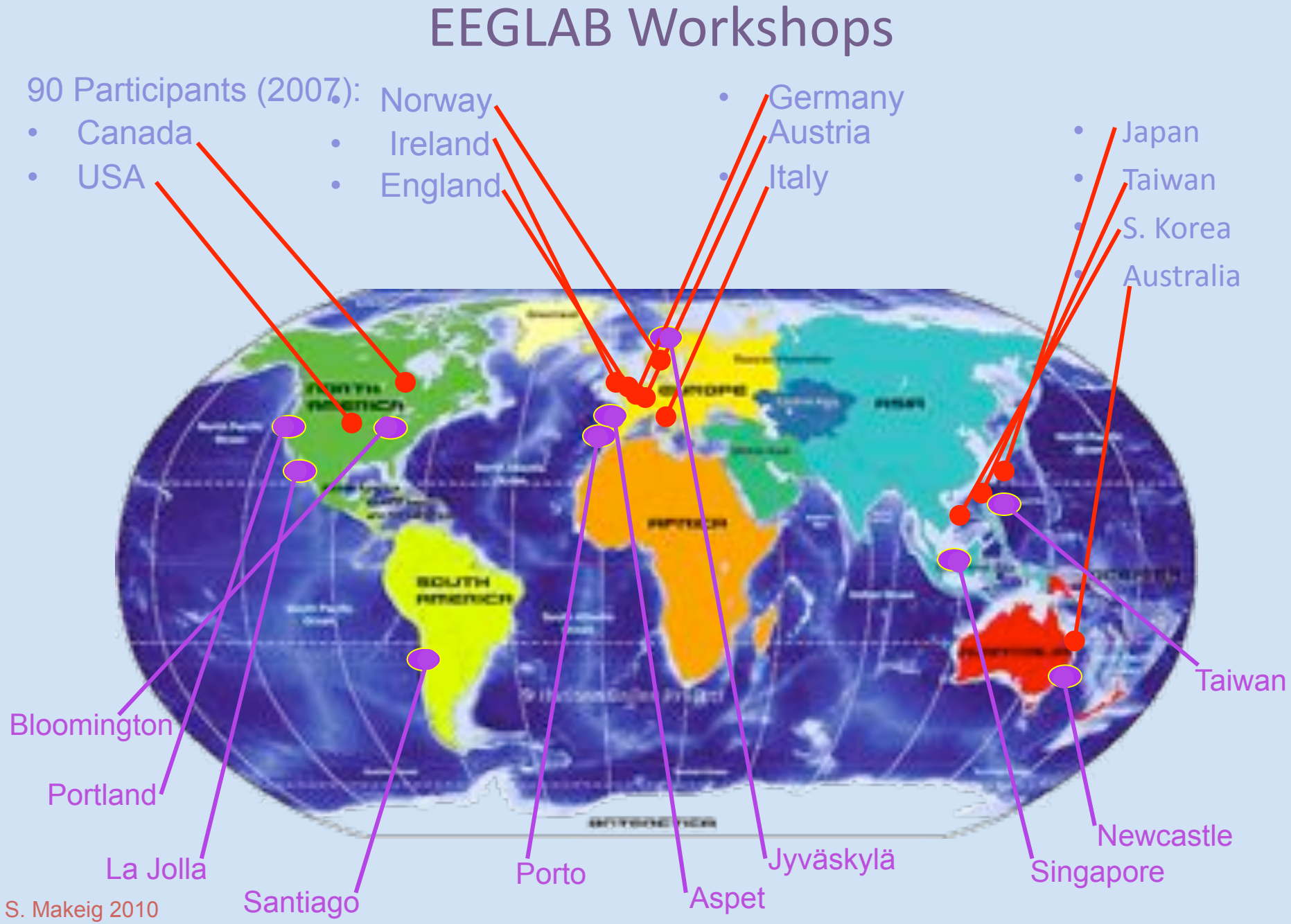
- ~200 EEGLAB downloads a week

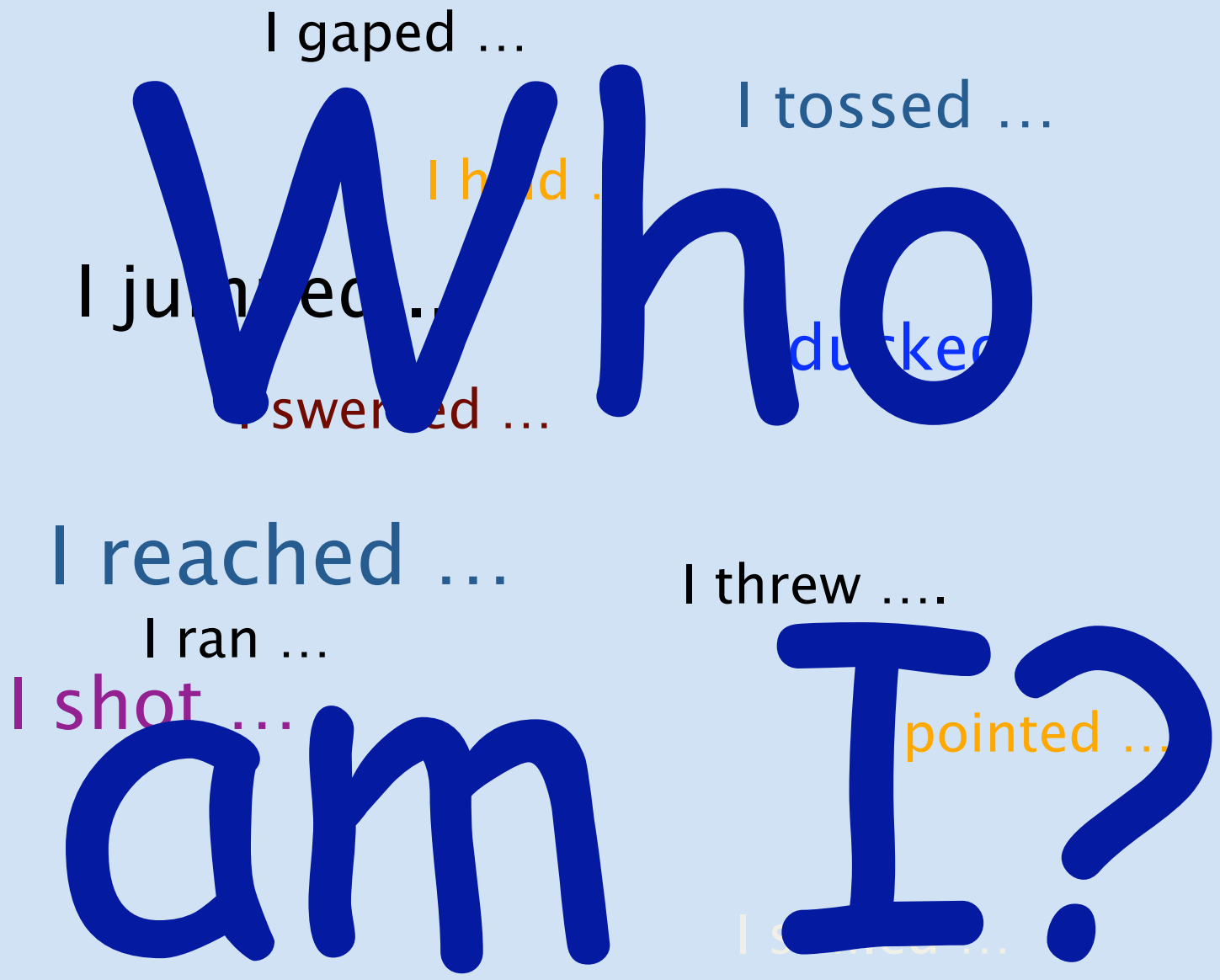
… all together to at least 90 country domains

- > 3,500 on the 'eeglablist' discussion list
- 20++ EEGLAB plug-ins available

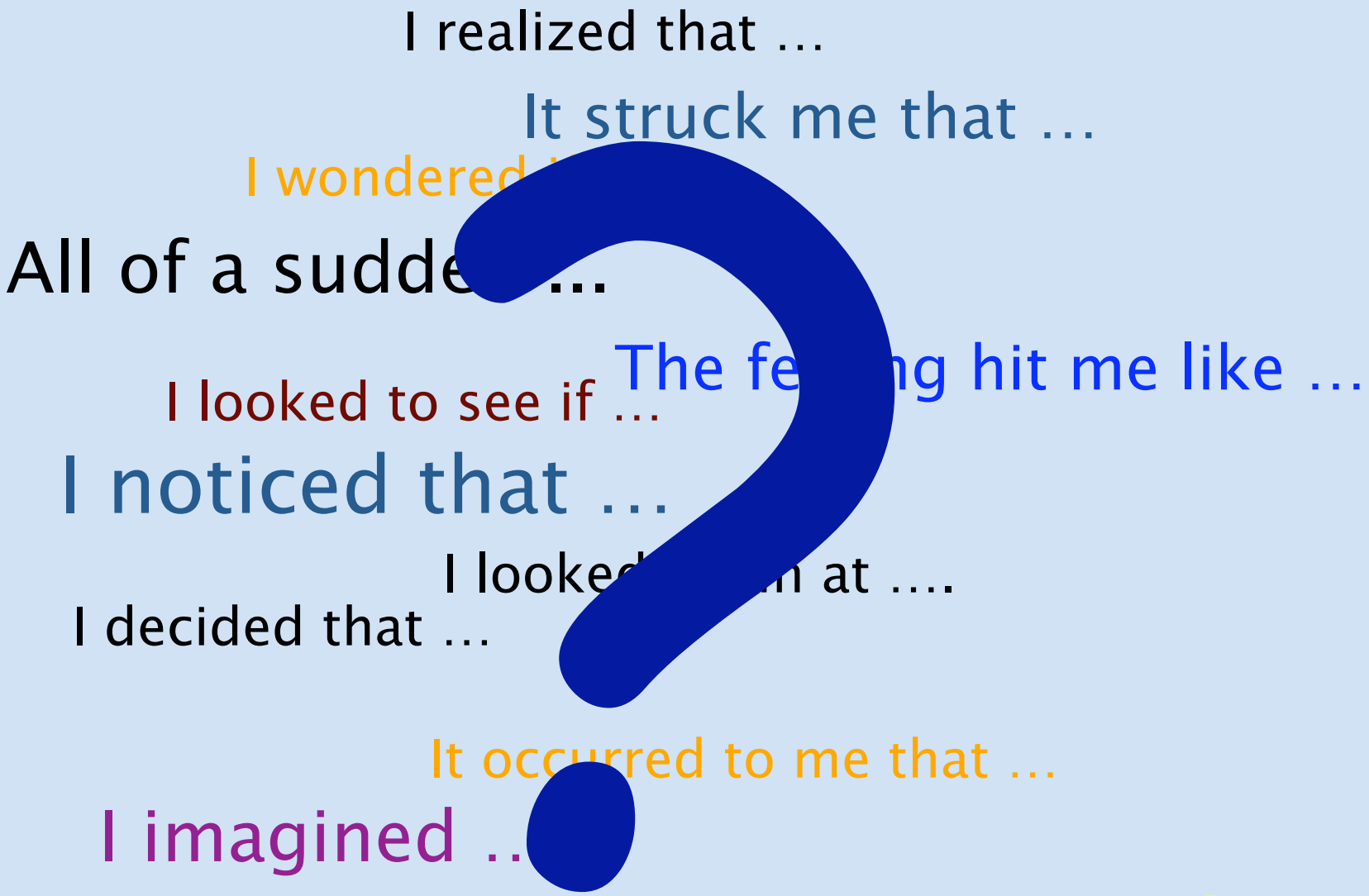
S. Makeig 2007

EEGLAB Workshops





S. Makeig 2001



S. Makeig 2001

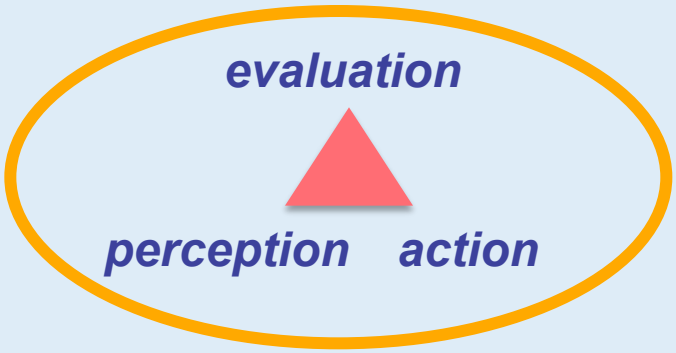
Dynamic Brain Events

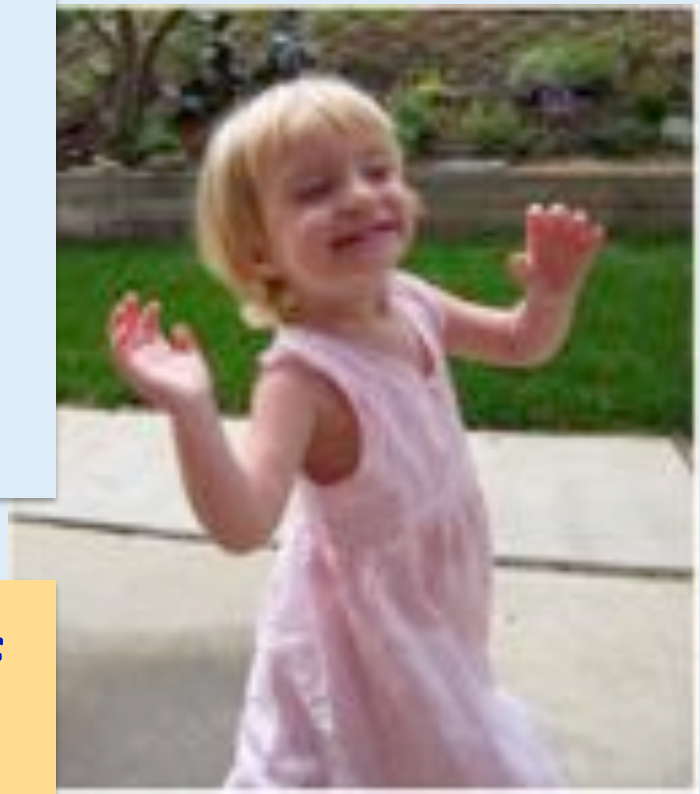
"When I went to the back of the house for a second time, I looked around more carefully. Some light came from the neighbors' on the other side of the grape-stake fence. I noticed that the back door of Stanley Broadhurst's house was slightly ajar. I opened it all the way and turned on the kitchen lights. There were marks around the lock which showed that it had been jimmied. It occurred to me that the guy who did the job might still be inside. … I turned off the kitchen light and waited. The house was silent. From outside I could hear the pulsing hum of the arterial boulevard I had just left."

- Ross MacDonald
The Underground Man

Embodied Cognition & Agency

Brain processes
have evolved and function
to optimize the ***outcome***
of the ***behavior***
the brain organizes
in response to
perceived challenges
and opportunities.





Brains meet the challenge of the moment!

Functional Brain Imaging

Some human brain imaging milestones

1926 ~1st human EEG recording

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 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).

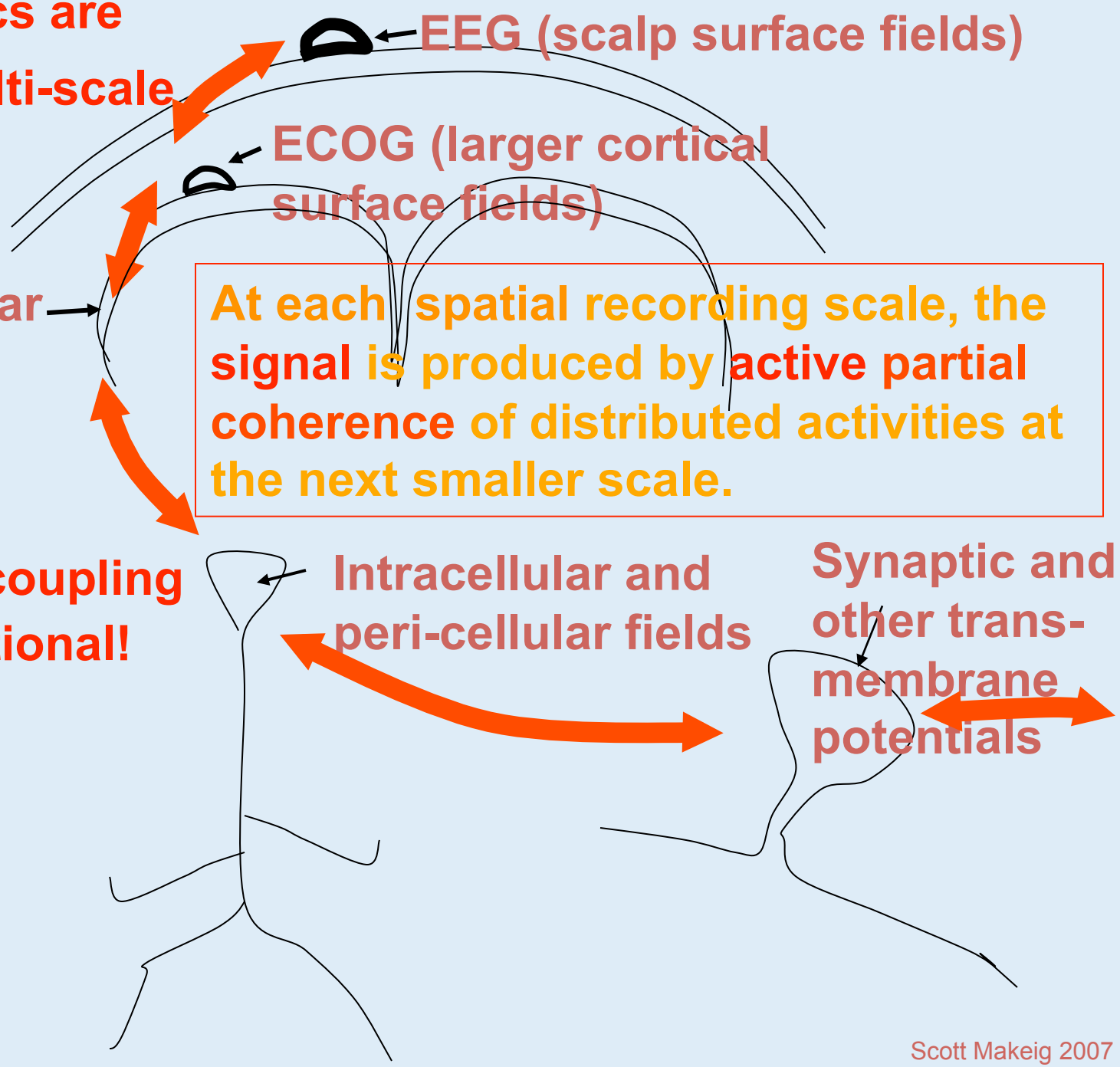
FIGURE 1-2.—Sample of the first EEG tracing taken at the Bradley Hospital, E. Providence, Rhode Island, by H. Jasper and L. Carmichael. Subject: Carl Pfaffmann. Date: July 9, 1934. Record, which shows prominent alpha rhythm of about 11.5 per second, was made with a Westinghouse, galvanometer-type, mirror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

S. Makeig 2010

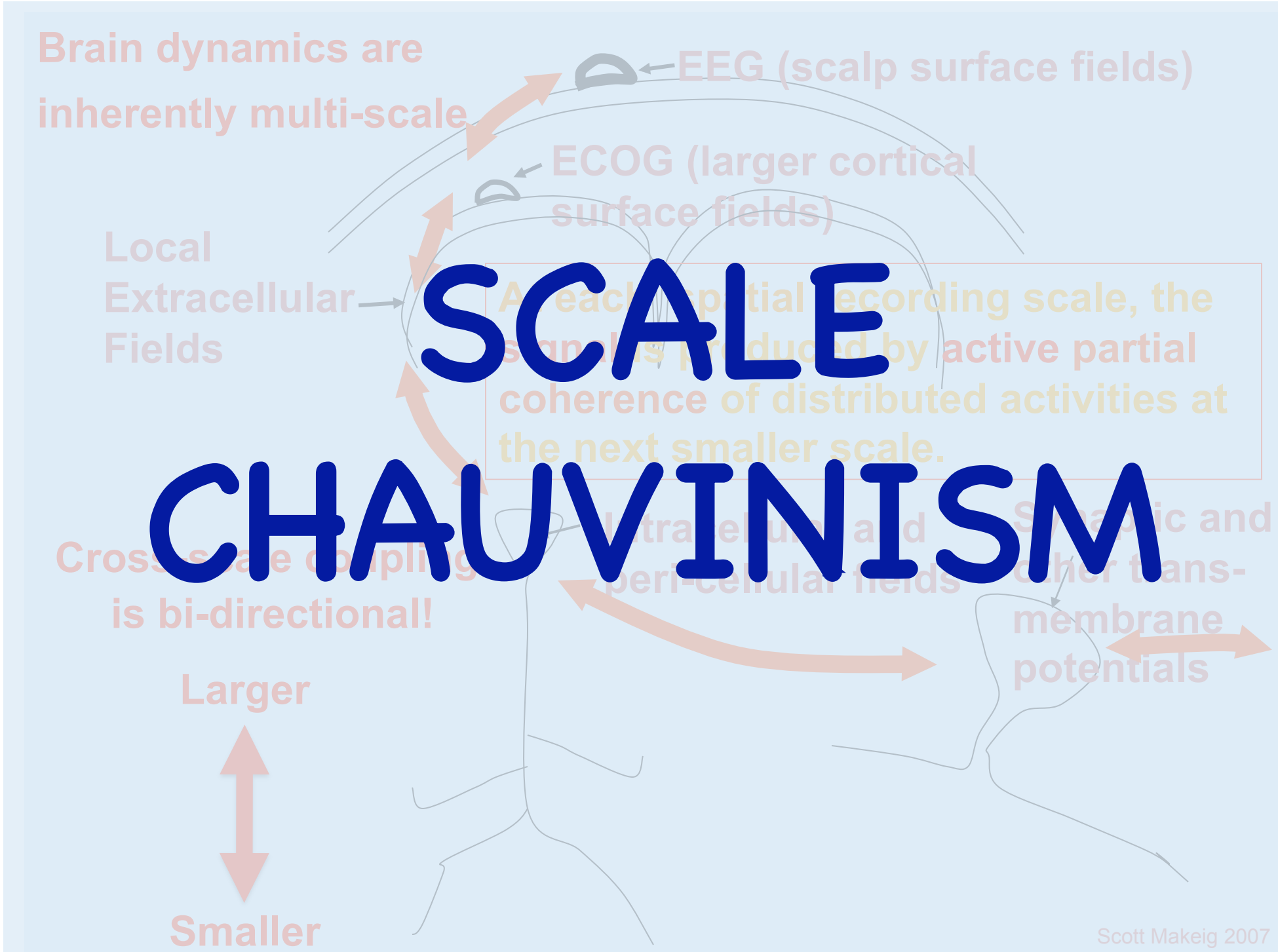
What is EEG?

Makeig (2006)

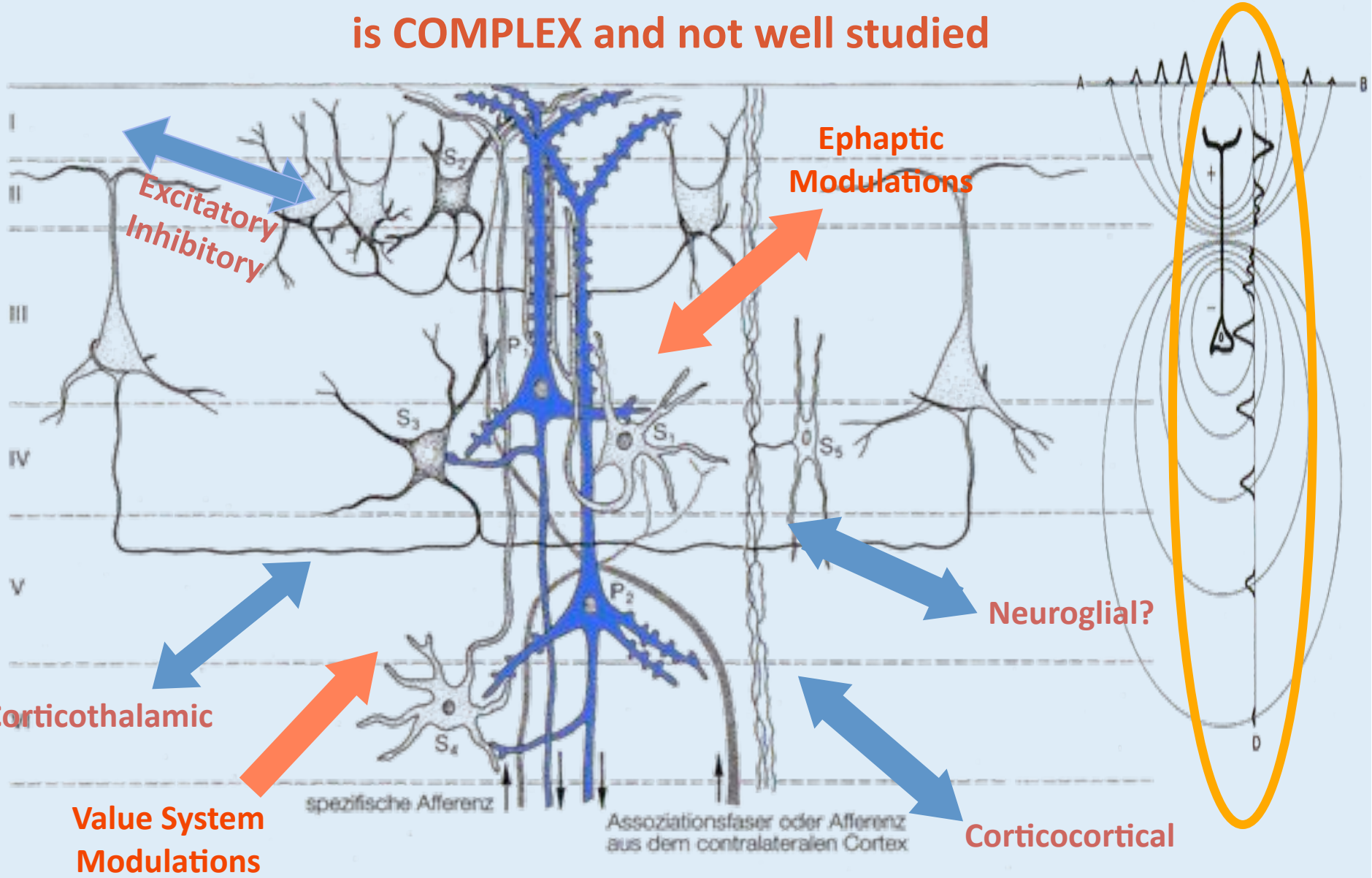
Brain dynamics are inherently multi-scale



Scott Makeig 2007


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 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 / LFP is COMPLEX and not well studied



S. Makeig 2007

Functional Brain Imaging

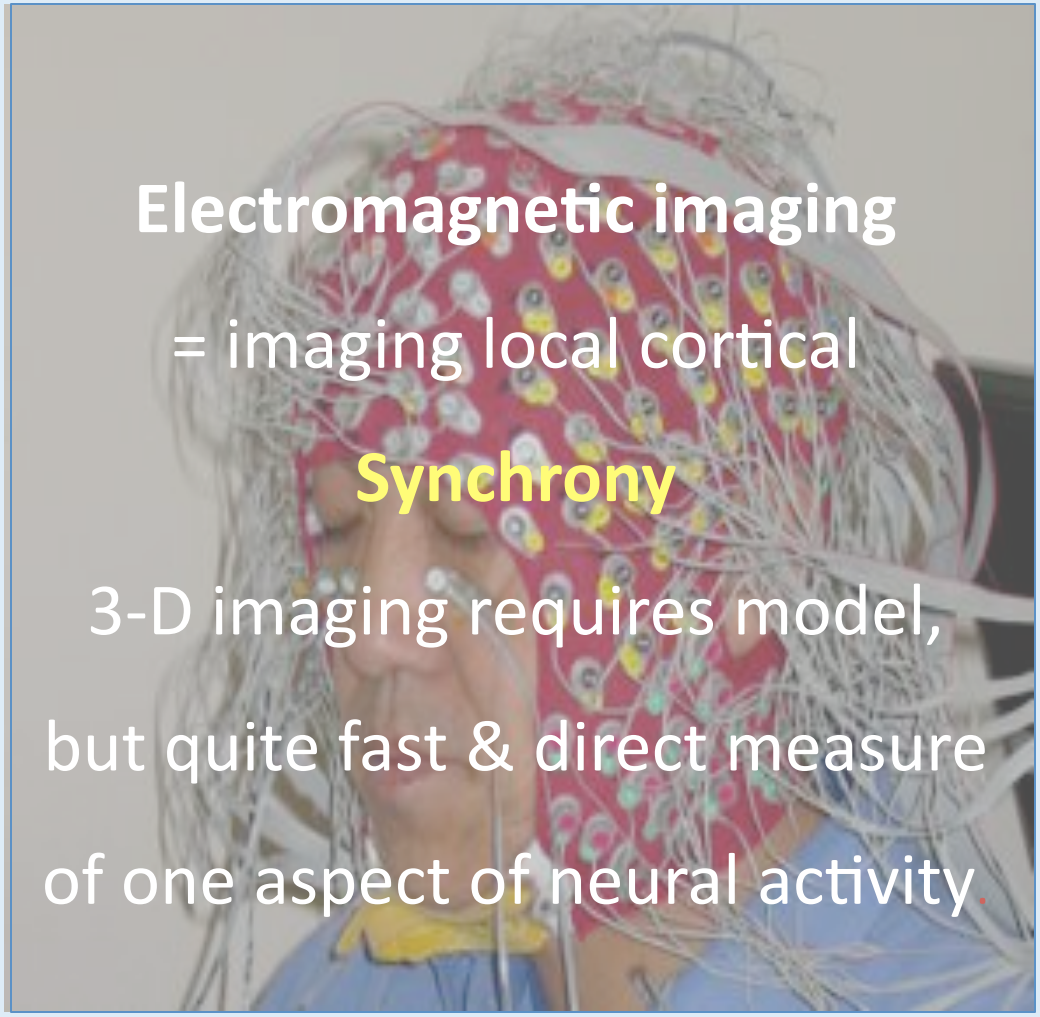
Hemodynamic imaging

= imaging brain

Energy

Direct 3-D inverse model,

but quite slow & indirect



Electromagnetic imaging

= imaging local cortical

Synchrony

3-D imaging requires model,

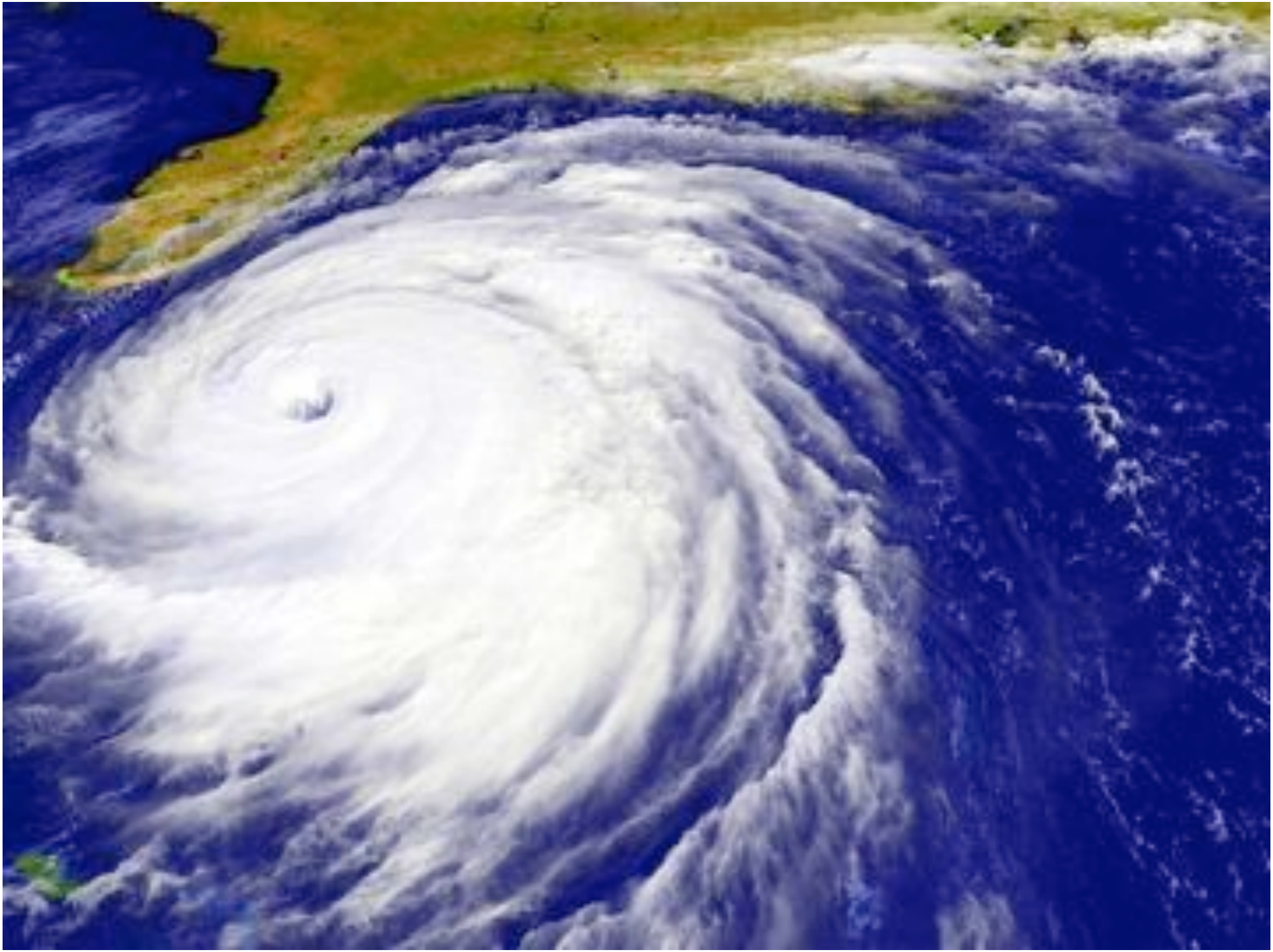
but quite fast & direct measure

of one aspect of neural activity.

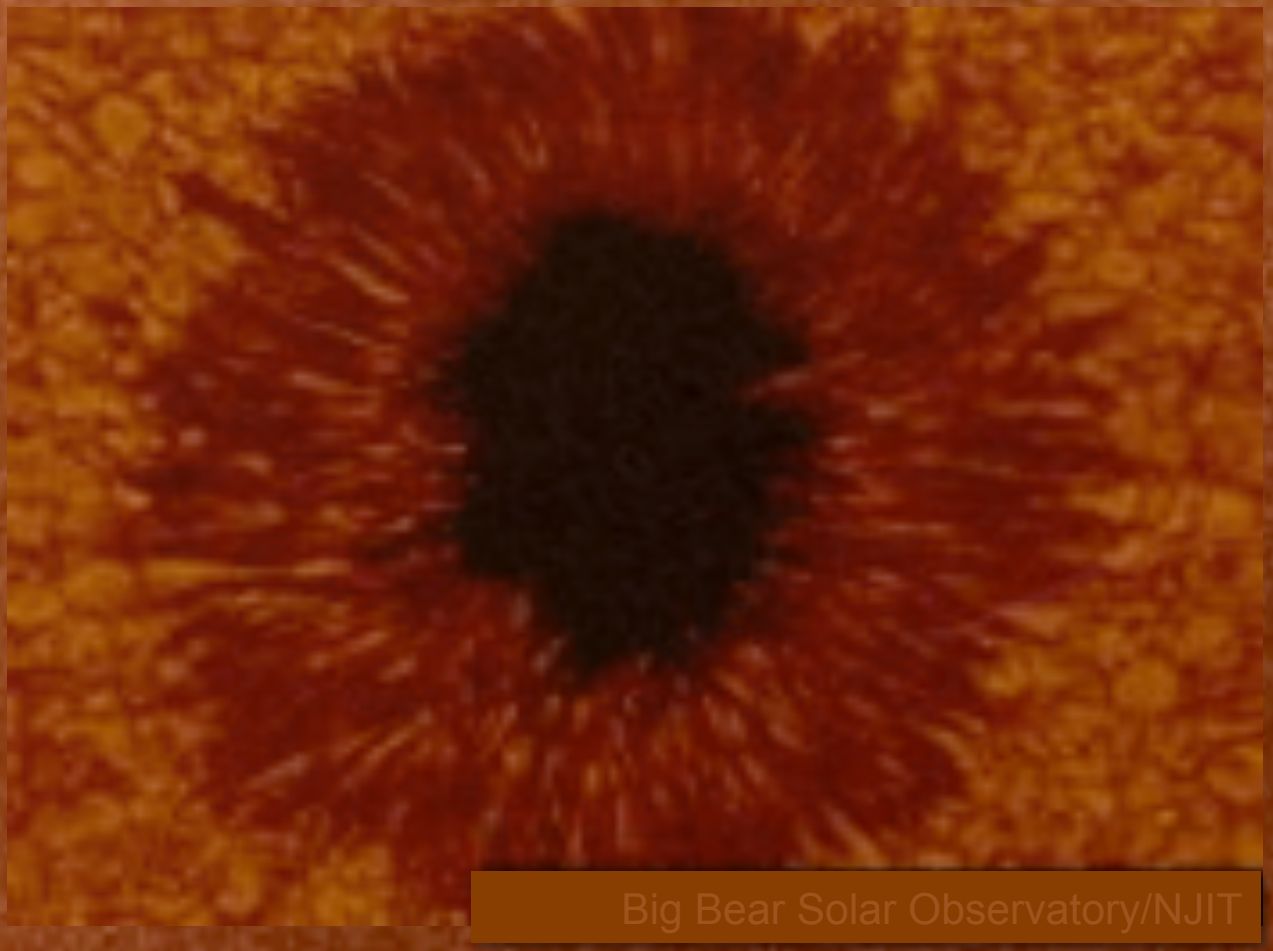
Phase cones (Freeman)

Avalanches (Plenz)

S. Makeig 2010

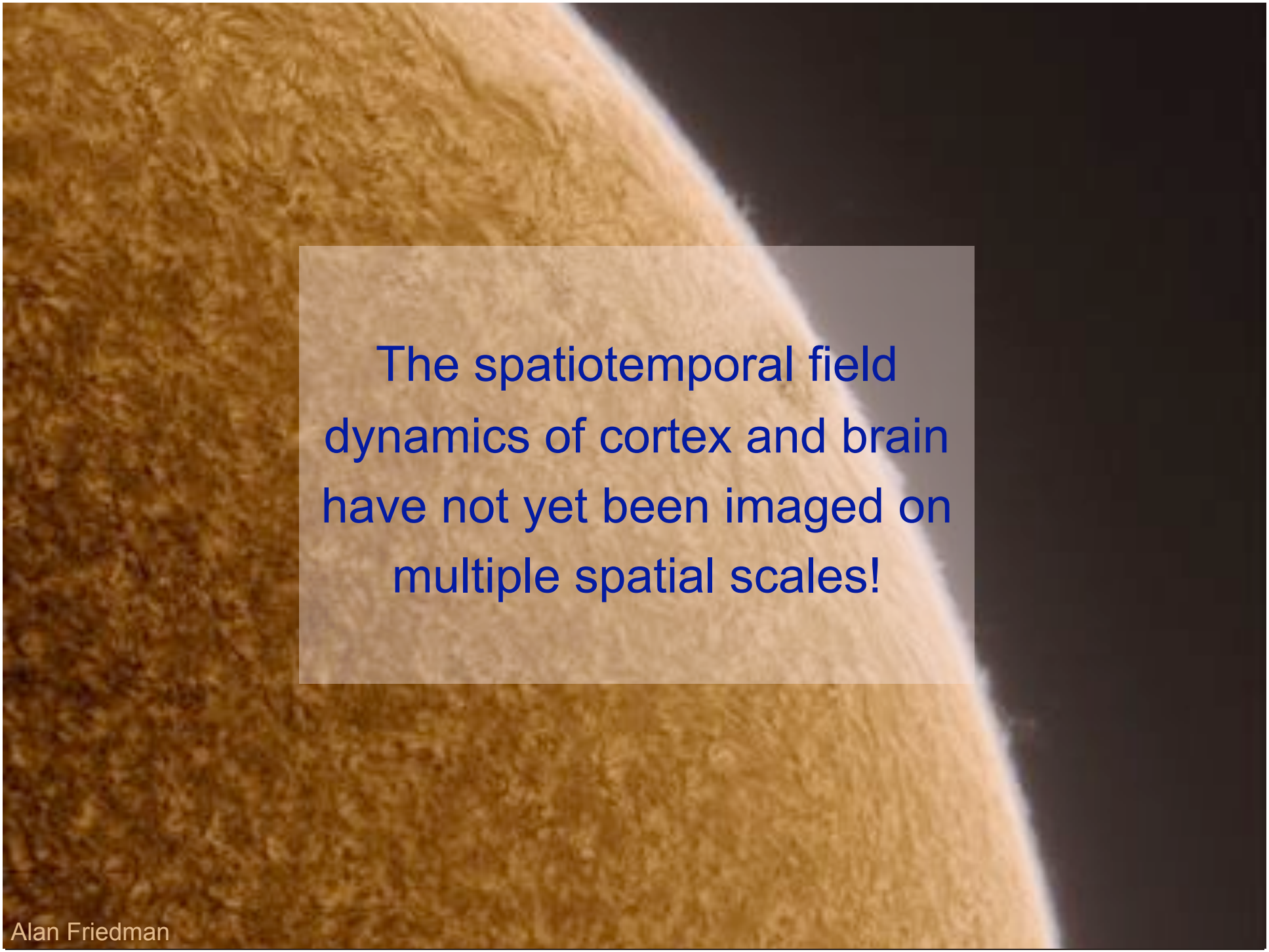


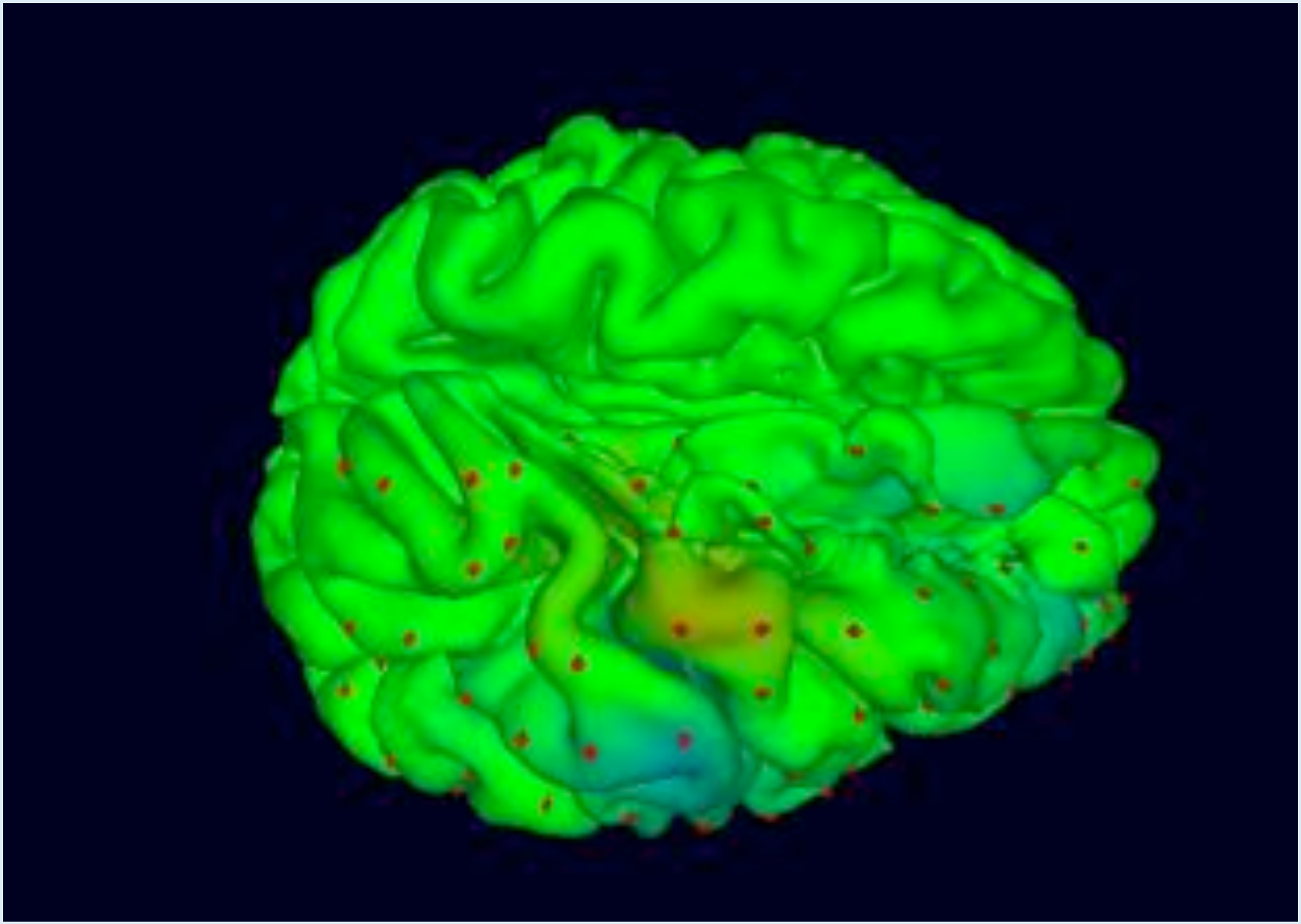

Macro field dynamics are spontaneous emergent dynamic patterns – in both outer space and cortex.
Scott Makeig 2008



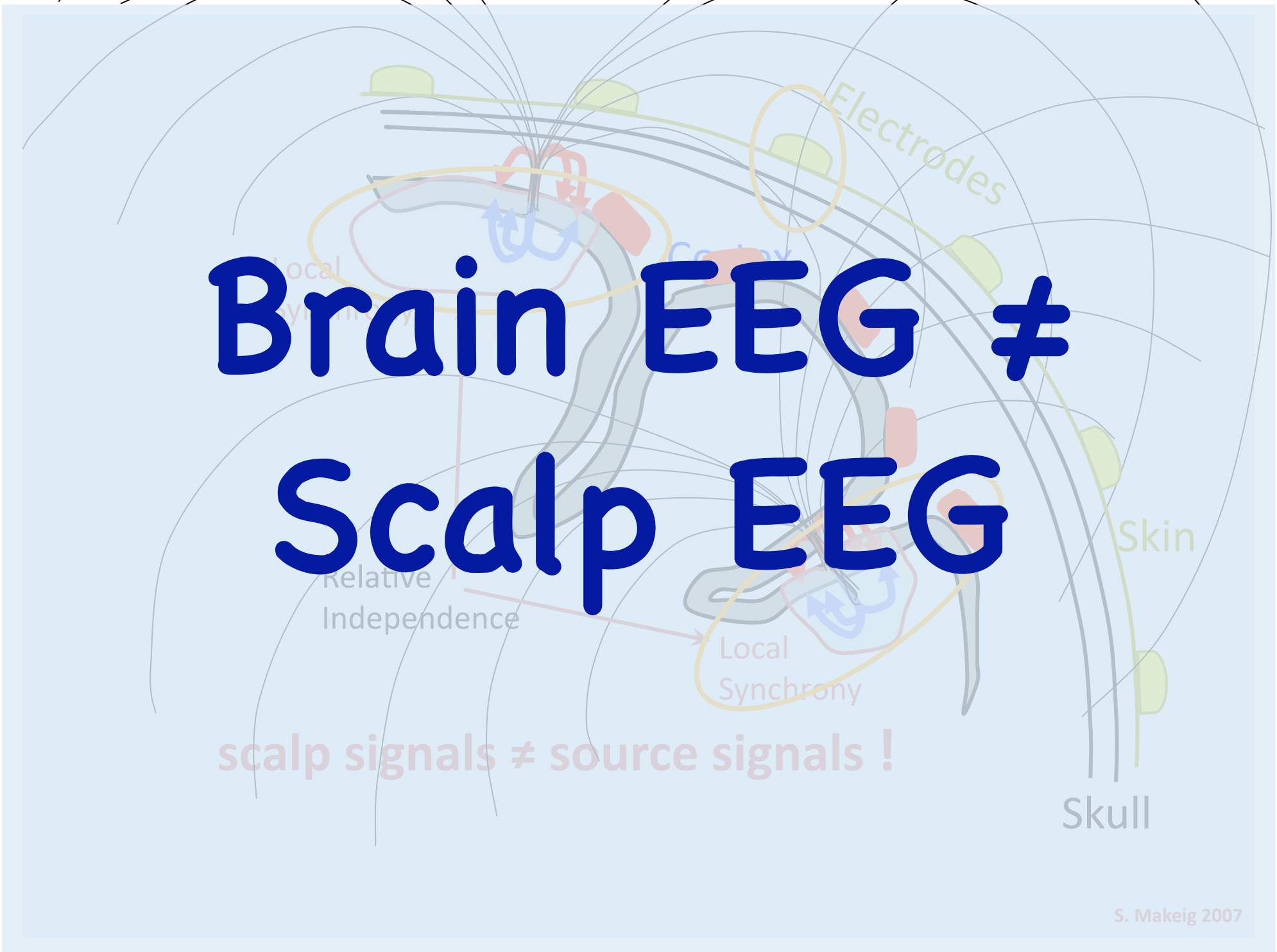
Big Bear Solar Observatory/NJIT

Alan Friedman

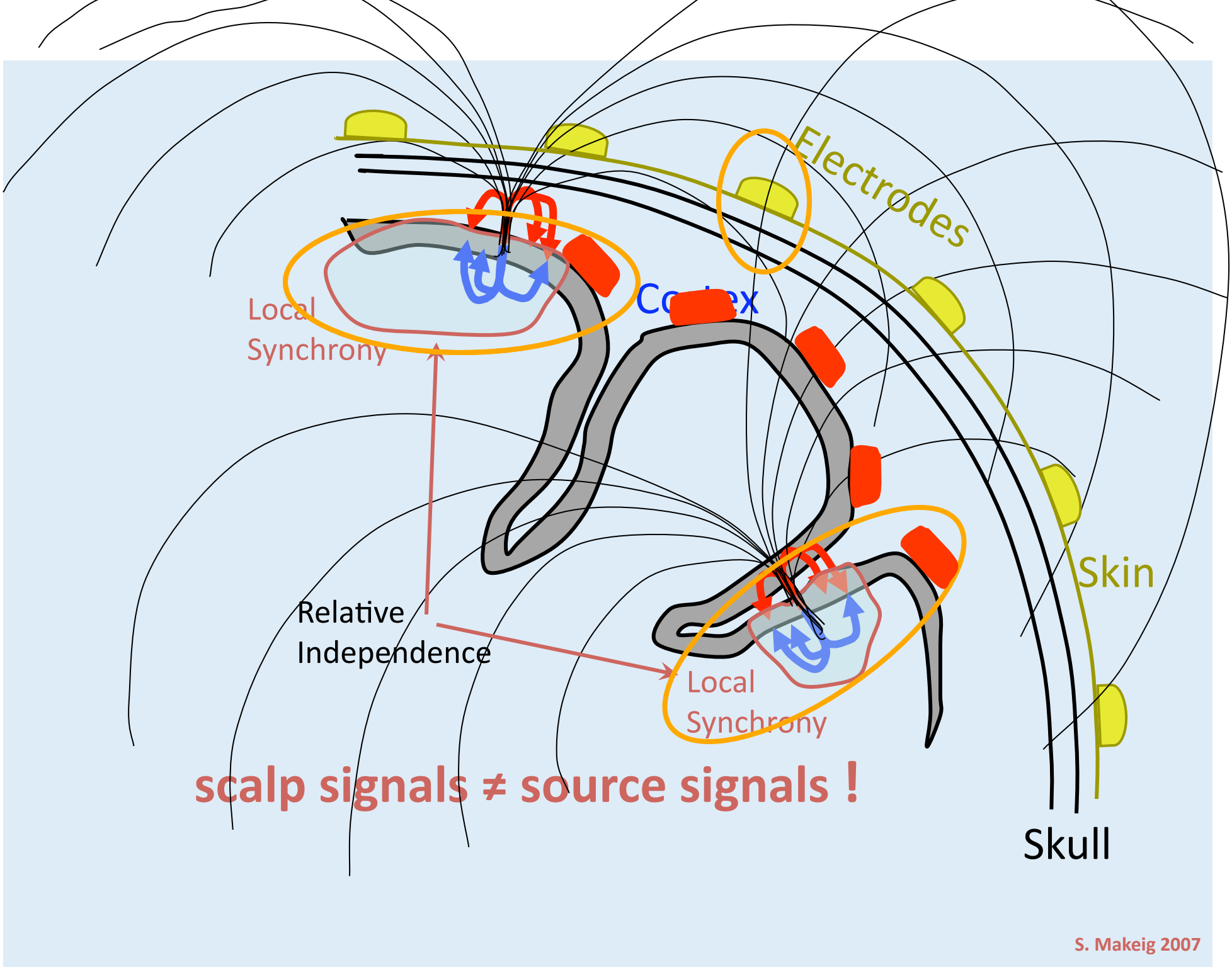

The spatiotemporal field dynamics of cortex and brain have not yet been imaged on multiple spatial scales!
Alan Friedman



Z. Akalin Acar, J. Palmer, G. Worrell, & Makeig 2010



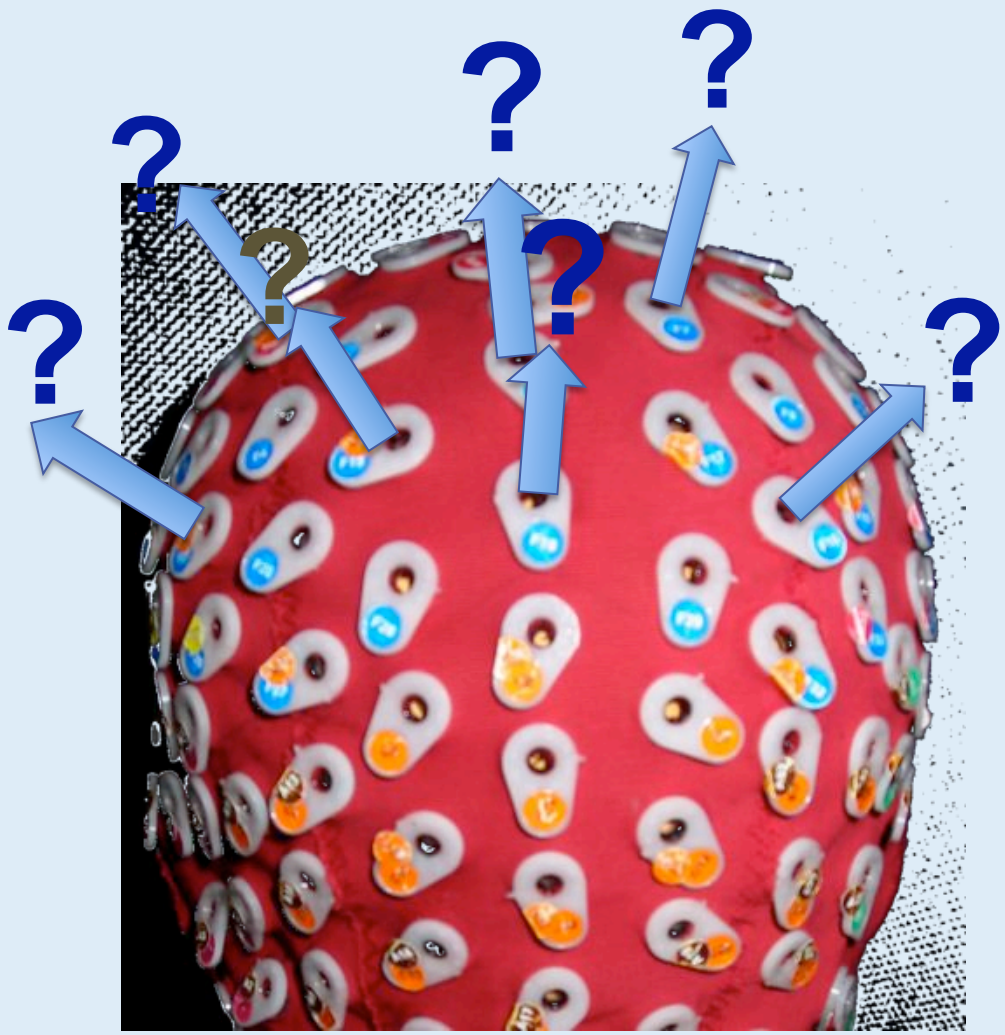
Brain EEG ≠ Scalp EEG



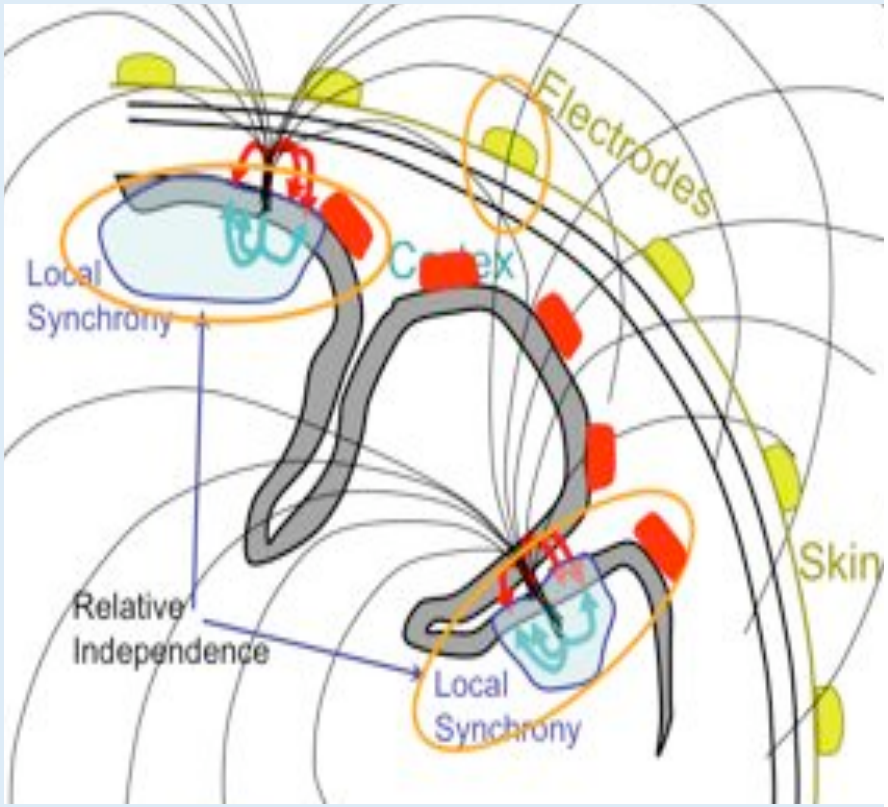
scalp signals ≠ source signals !

S. Makeig 2007

Naïve 2-D interpretation of EEG signals?



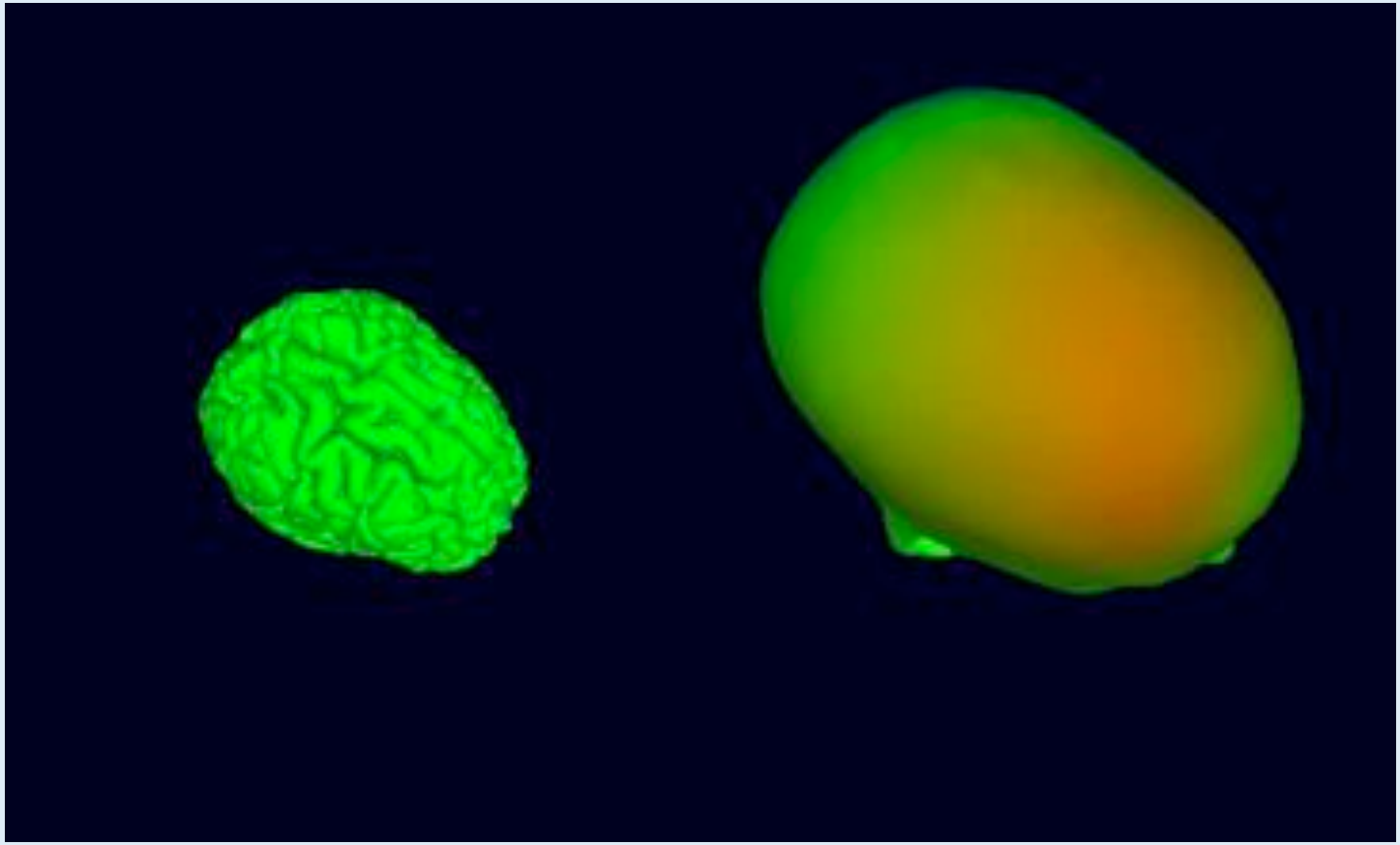
Cortical EEG signal projection patterns as point processes



Actual cortical source volume conduction patterns (cartoon)

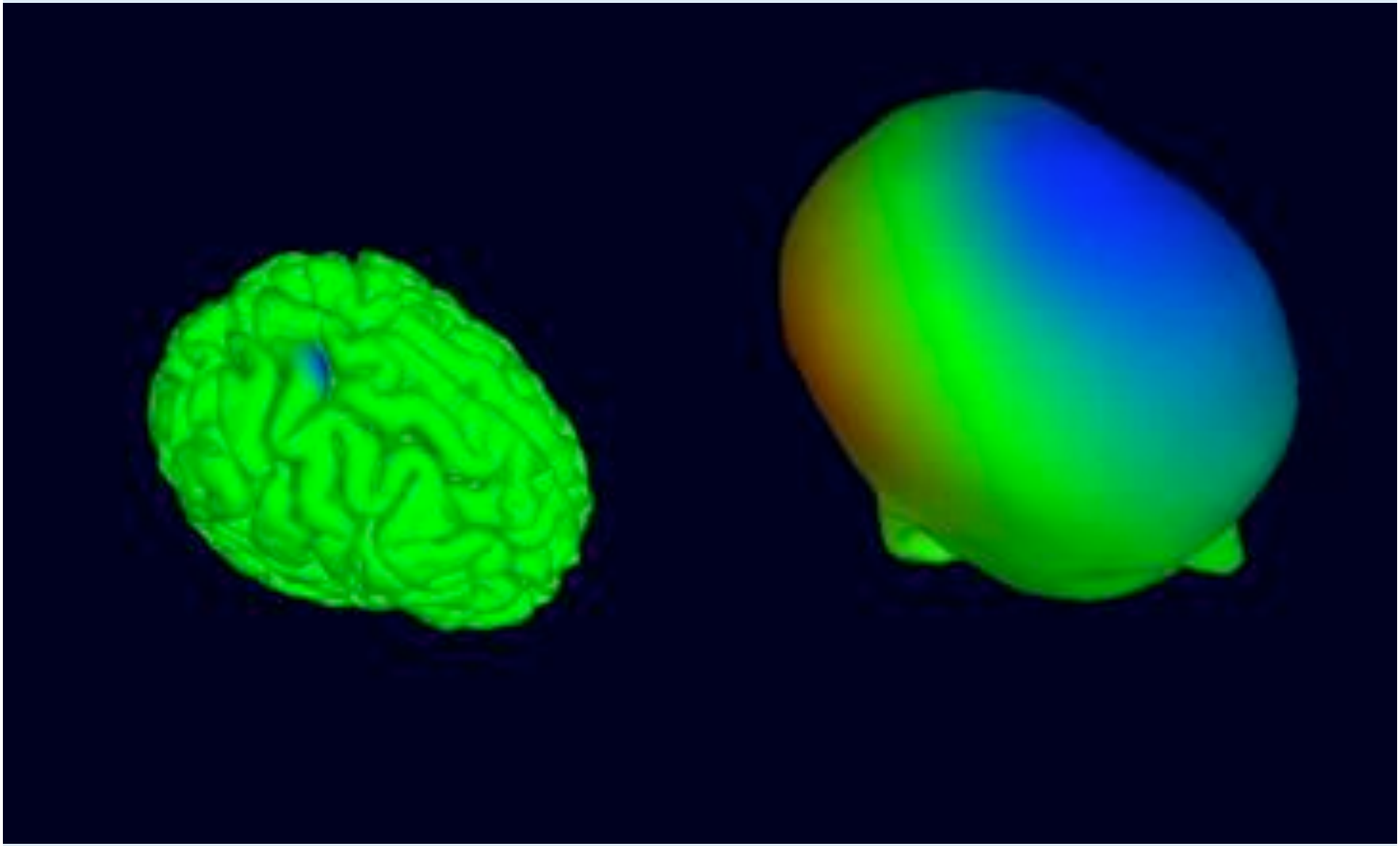
“Surely, Dr. Lowe, if there were gravity waves, we would have detected them by now.”

The very broad EEG point-spread function



Z. Akalin Acar & S. Makeig 2010

The very broad EEG point-spread function



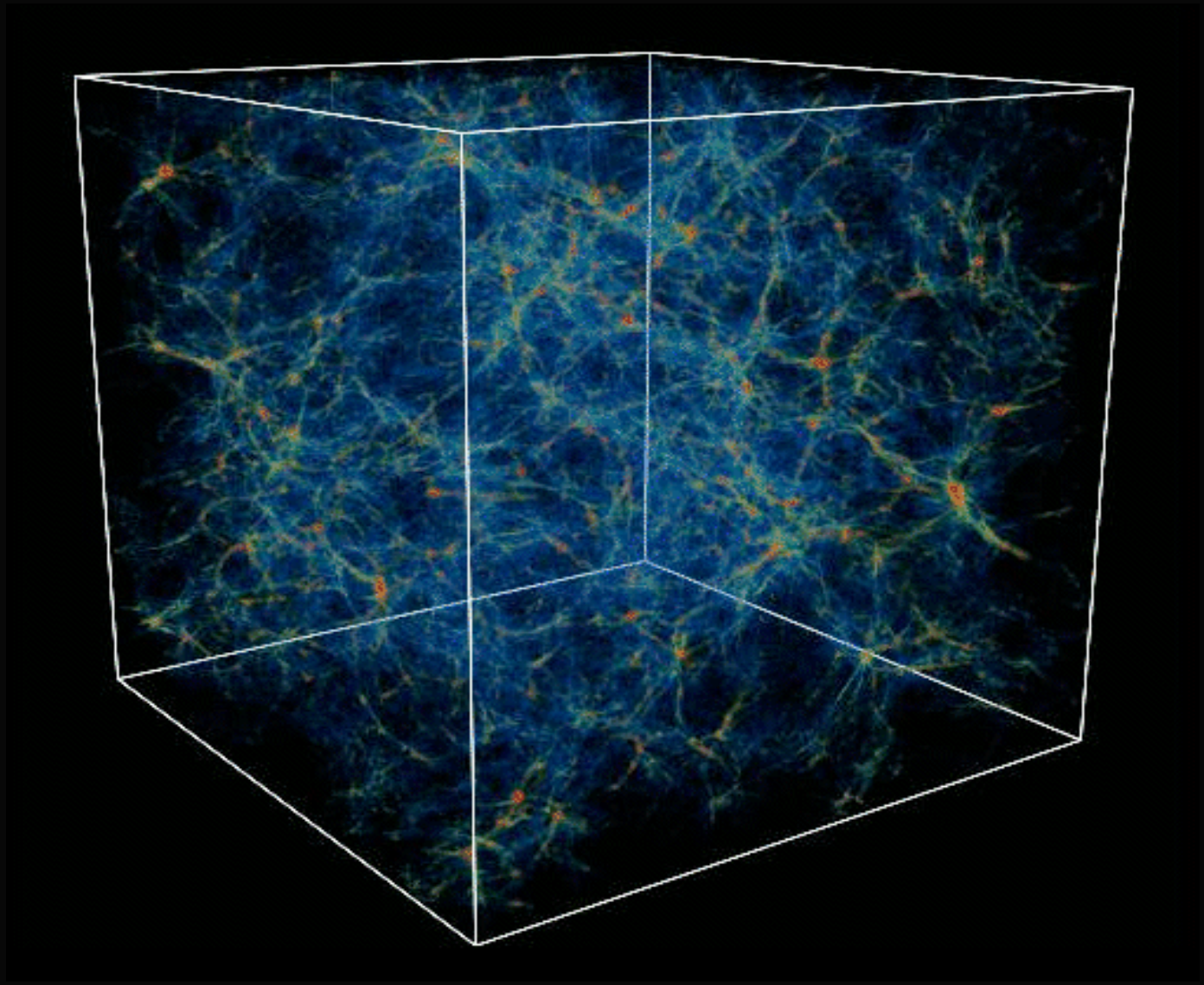
Single spatially labile source

Z. Akalin Acar & S. Makeig 2010

The Dome of the Sky

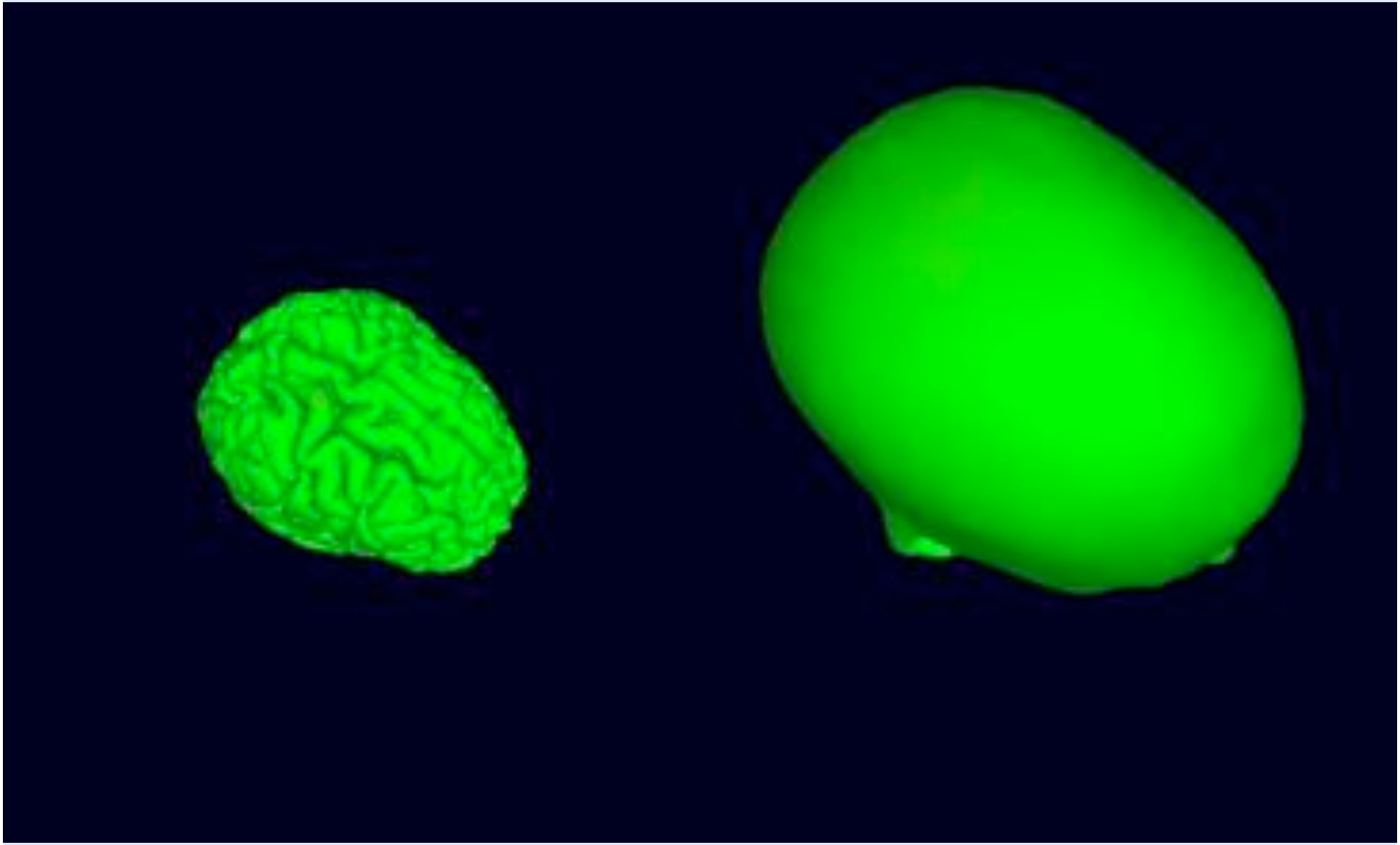
Stephen L. Alvarez

3-D structure of the Universe



NASA 2009

The very broad EEG point-spread function

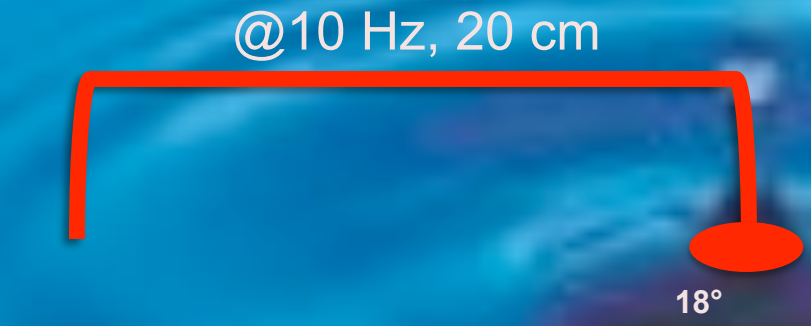


Spatially static cortical patch source

Z. Akalin Acar & S. Makeig 2010

Phase cones (Freeman)

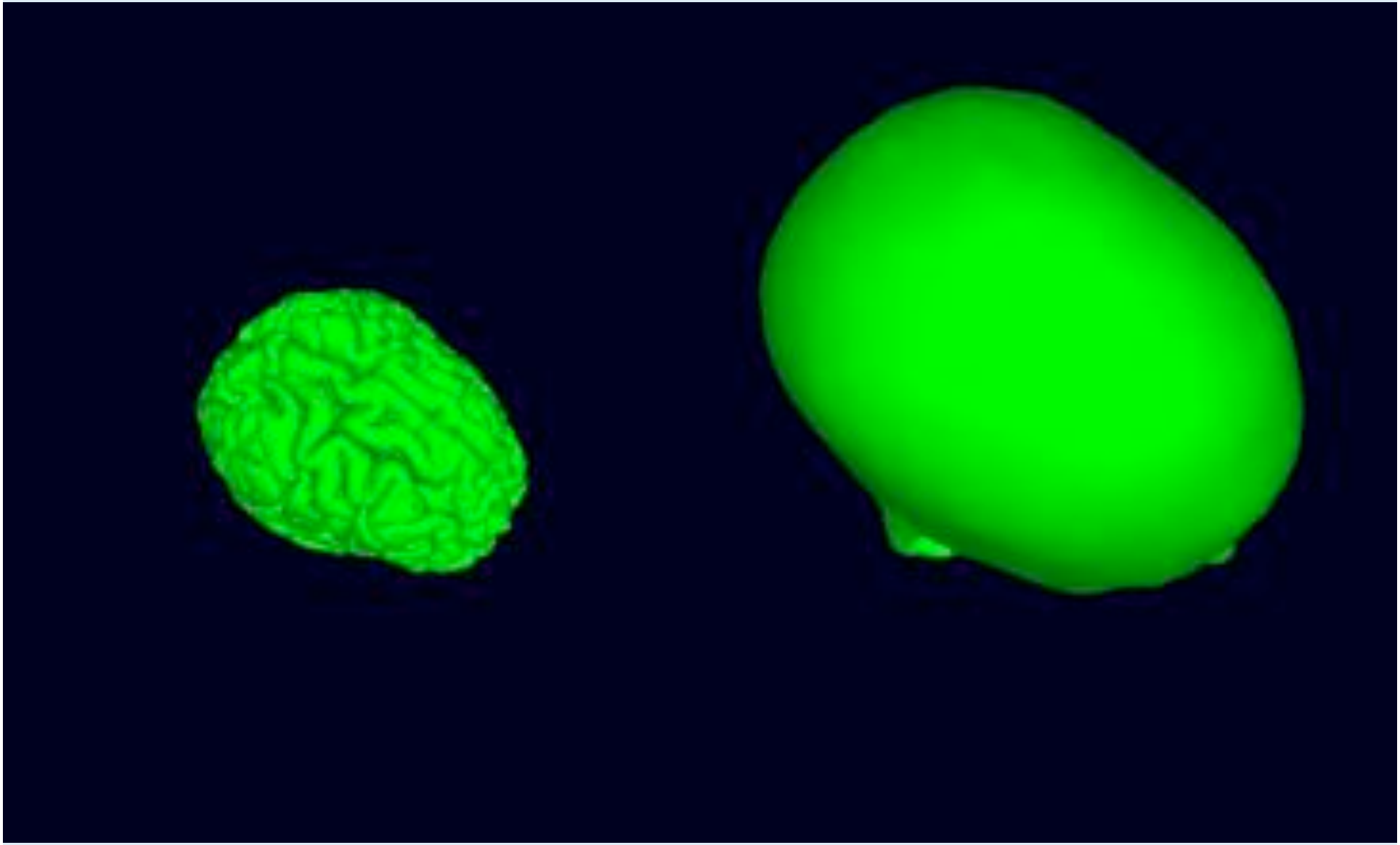
Avalanches (Plenz)



360°

0°

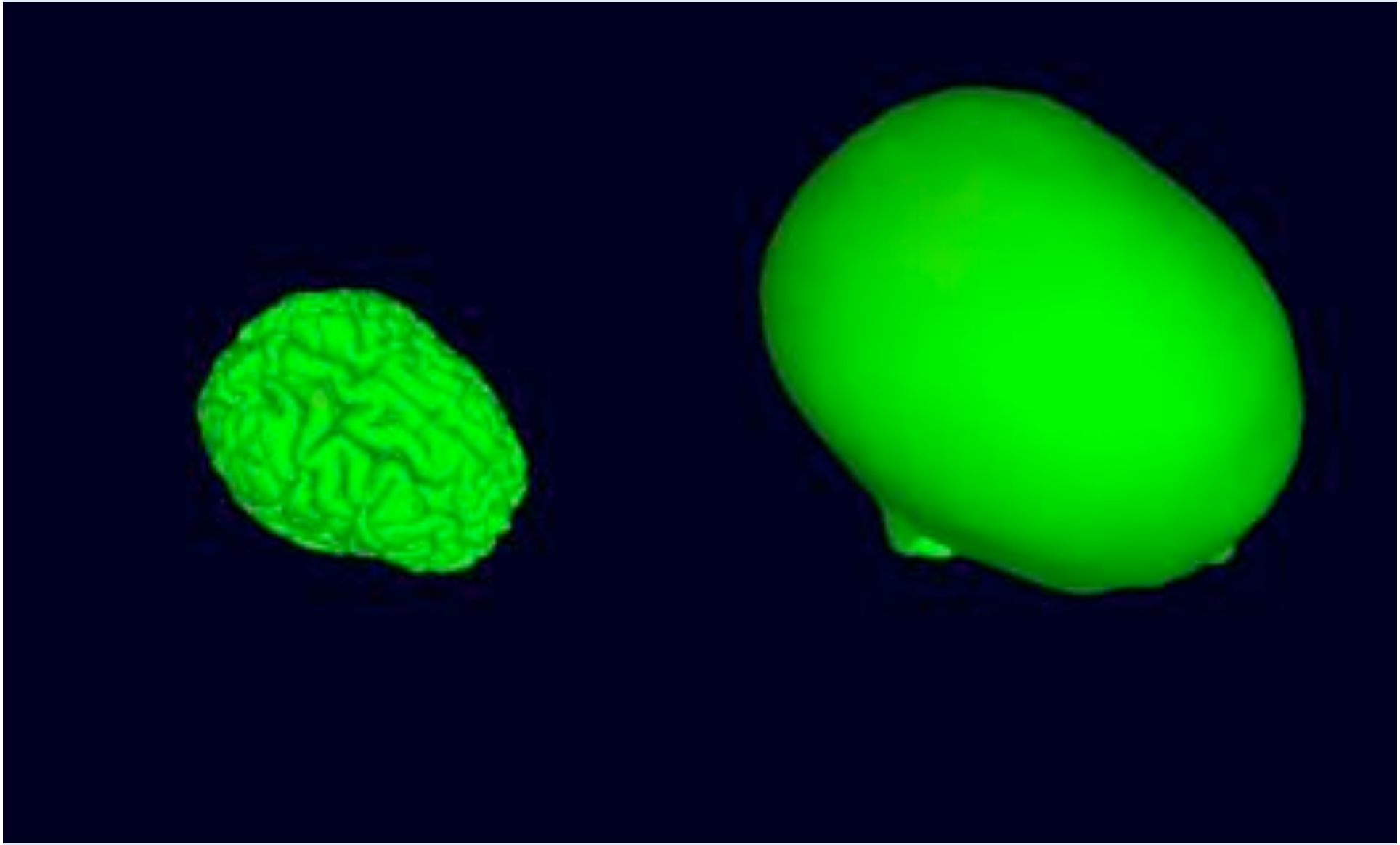
The very broad EEG point-spread function



Phase lag, center to edge: 18°

Z. Akalin Acar & S. Makeig 2010

The very broad EEG point-spread function

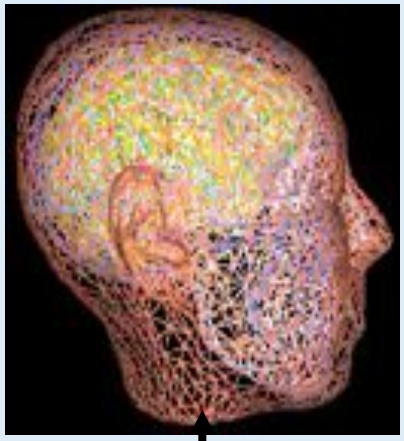


Phase lag, center to edge: 0°

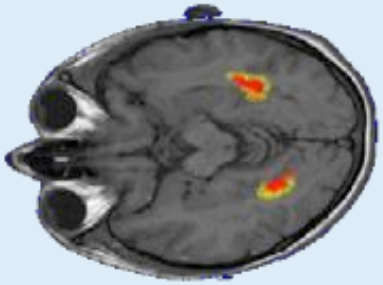
Z. Akalin Acar & S. Makeig 2010

Electromagnetic source localization

Solve the forward problem using realistic head models (BEM)



Simple Map



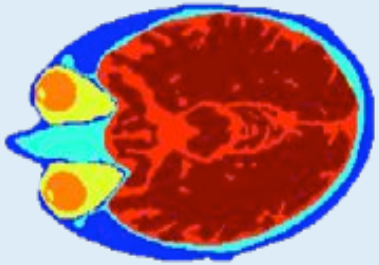
Source Image

Mesh generation

Sensor Localization

Signal Processing

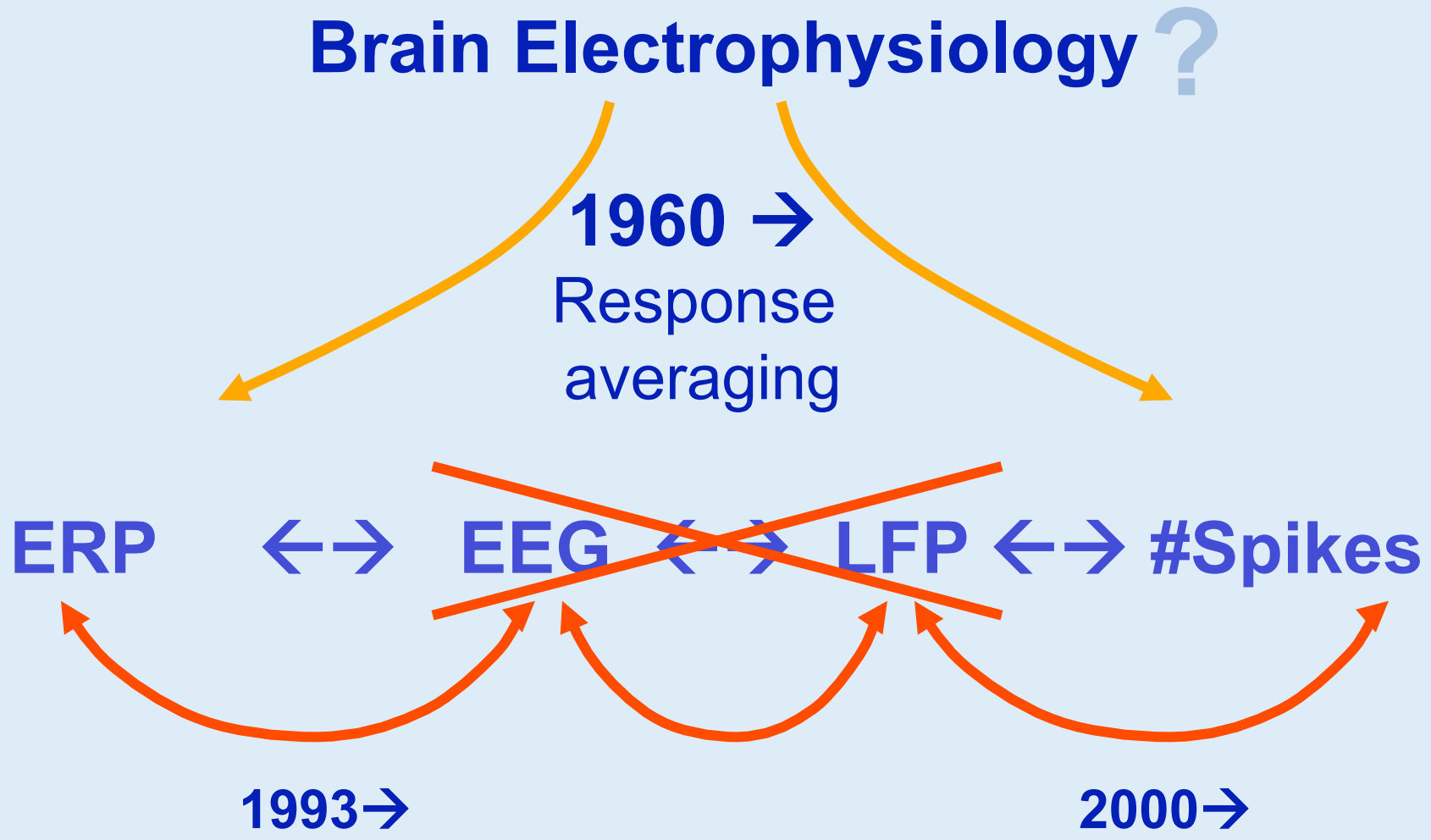
MRI



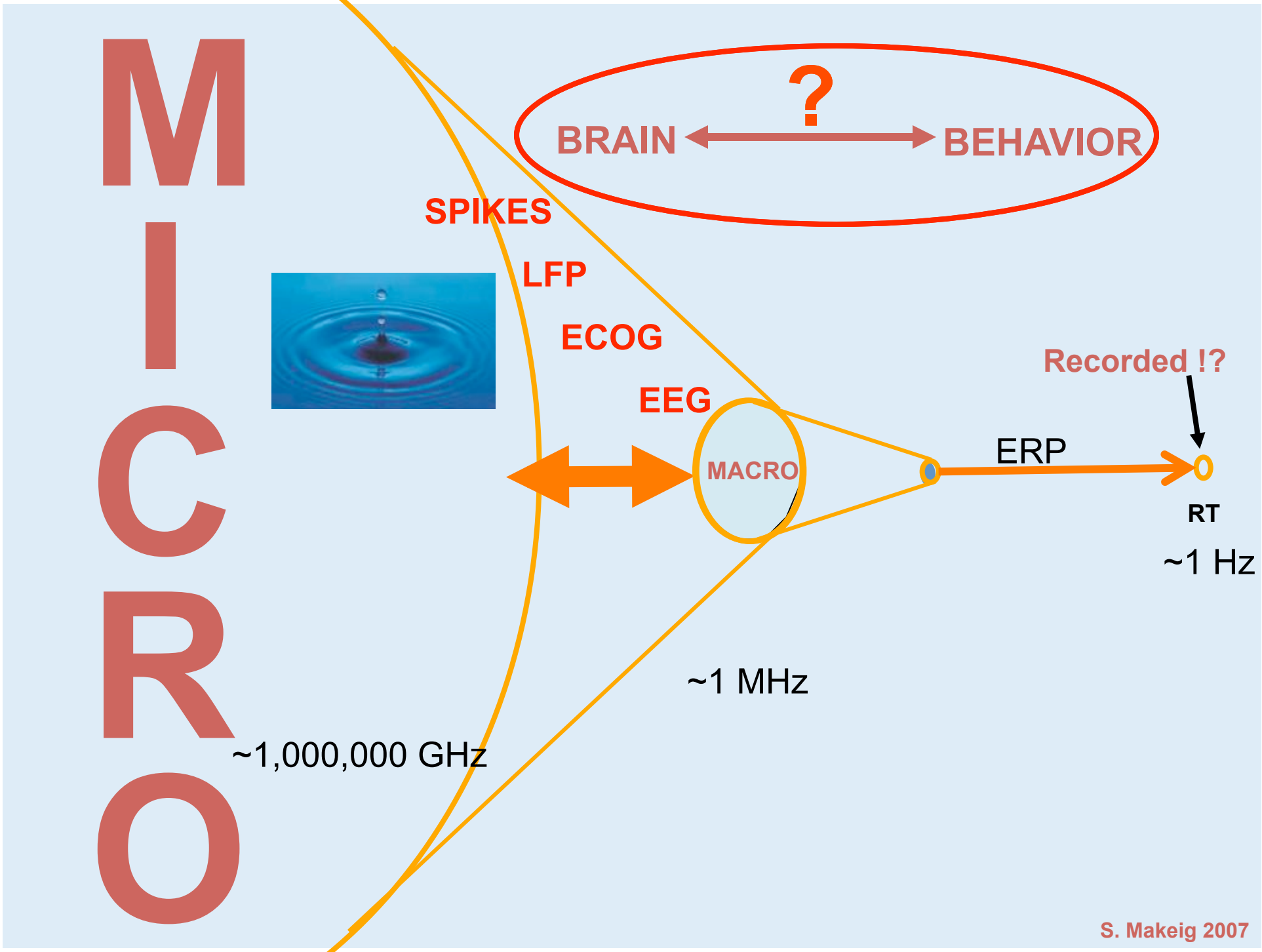
Segmentation

EEG/MEG

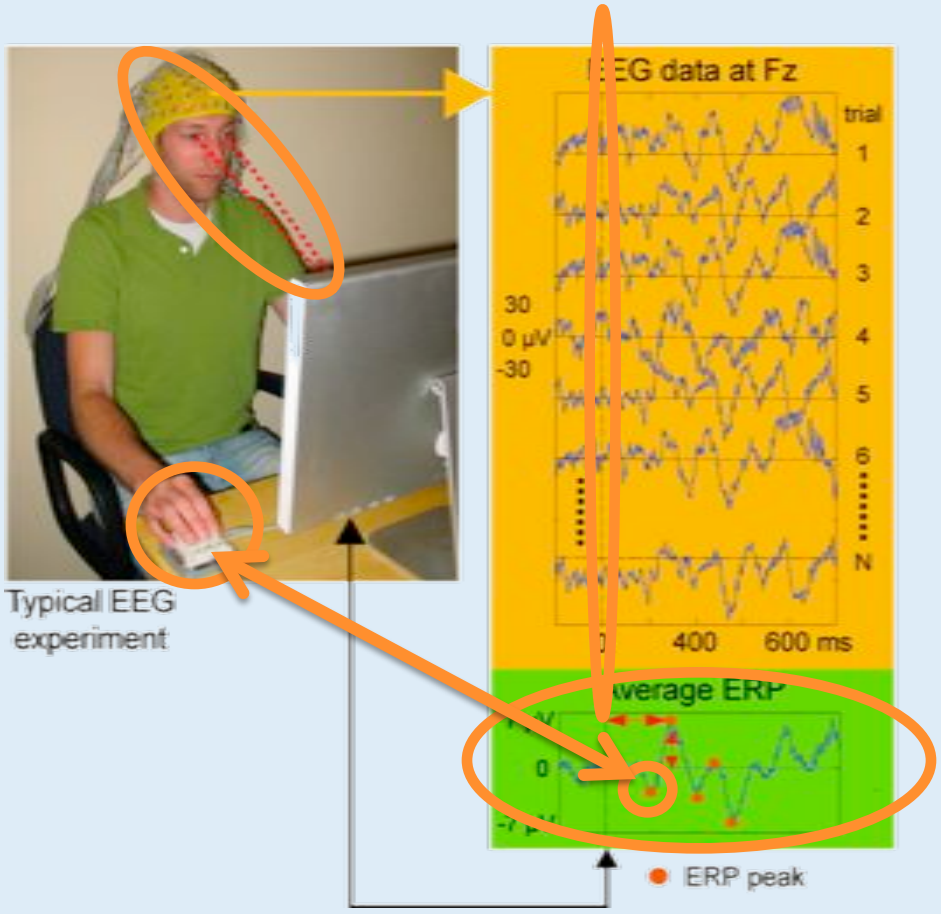
Zeynep Akalin Acar, & Scott Makeig '06



S. Makeig, *TINS* 2002


MICRO
BRAIN
?
BEHAVIOR
SPIKES
LFP
ECOG
EEG
MACRO
ERP
Recorded !?
RT
~1 Hz
~1 MHz
~1,000,000 GHz
S. Makeig 2007

Studying ‘cognitive perception’ using ERPs



Scott Makeig, 2008

The response averaging model:

EEG	ERP	EEG "noise"
Data	**≡ Average +**	**"Background"**
BOLD	ERB	BOLD "noise"

But, this linear decomposition is veridical if & only if:

Not True / Not Defined

1. The **Average** appears in each trial.

2. The **"Background"** is not perturbed in other ways by the time locking events.

Not True

Conceptual legacies of single sensor response/rate averaging

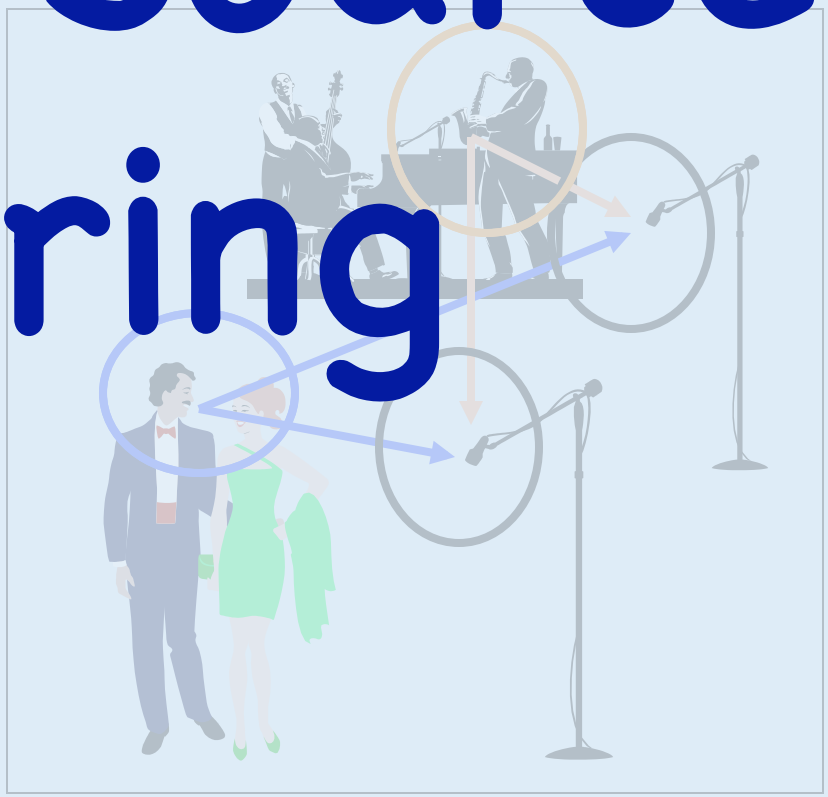
- Reduction of the time series data at each channel to a **single average response time series**.

- Reduction of the data collected at each channel to an **isolated spatial point process**.

How to capture more of the event-related brain dynamics contained in high-density EEG data?

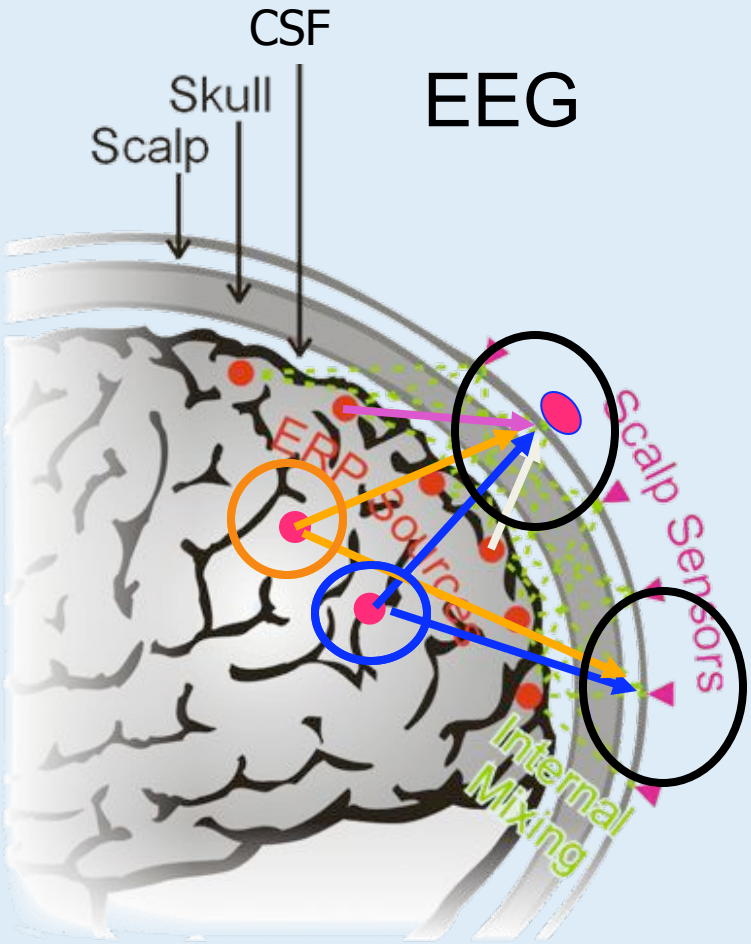
Blind EEG Source Separation by
Independent Component Analysis

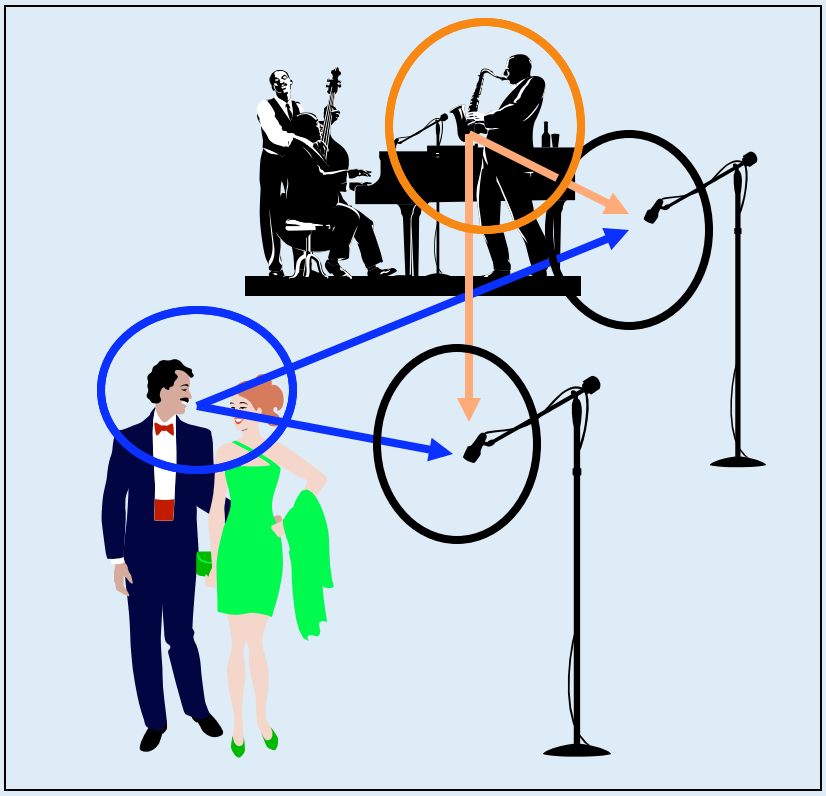
Spatial Source Filtering



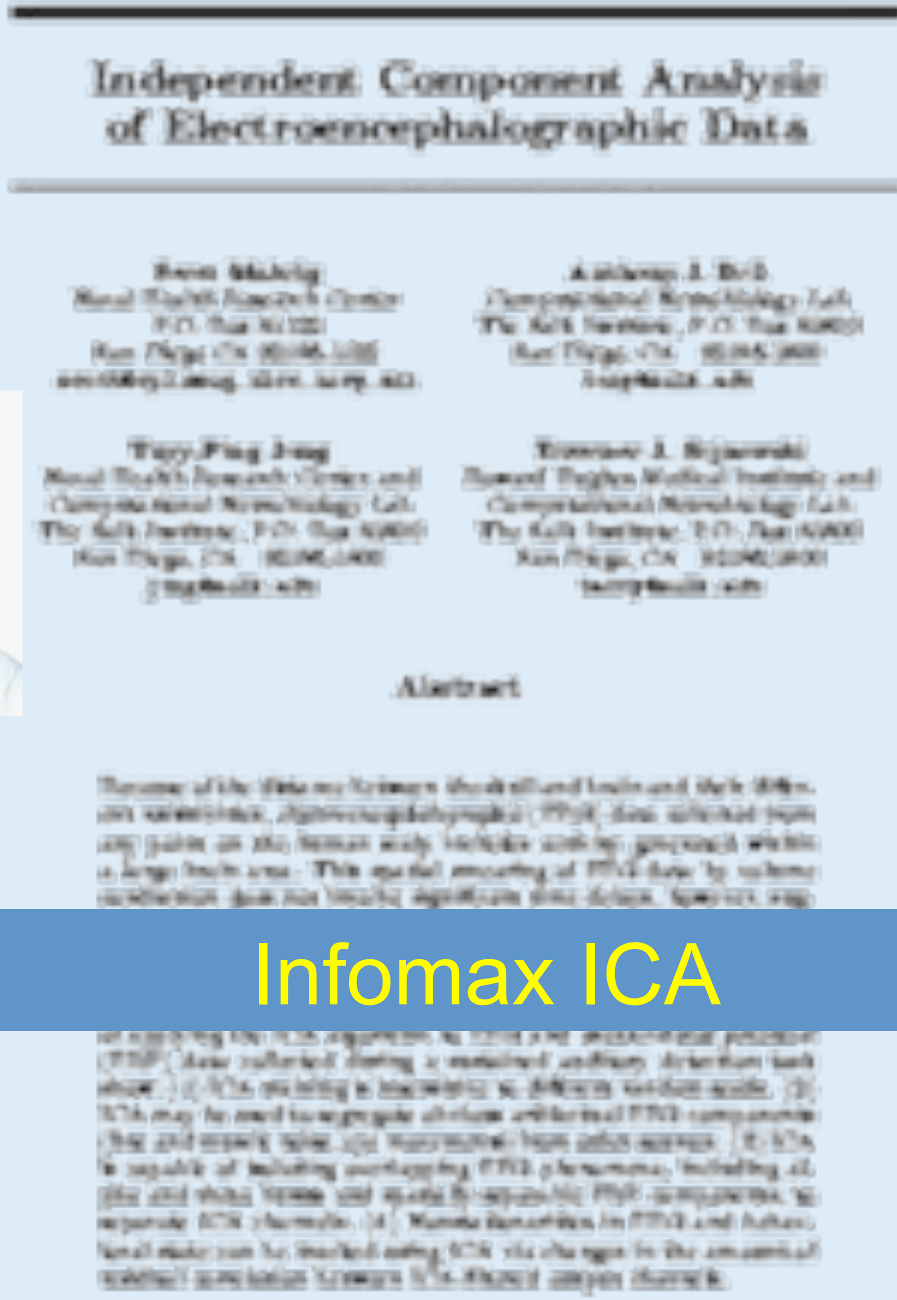
S. Makeig (2000)

Blind EEG Source Separation by Independent Component Analysis





S. Makeig (2000)

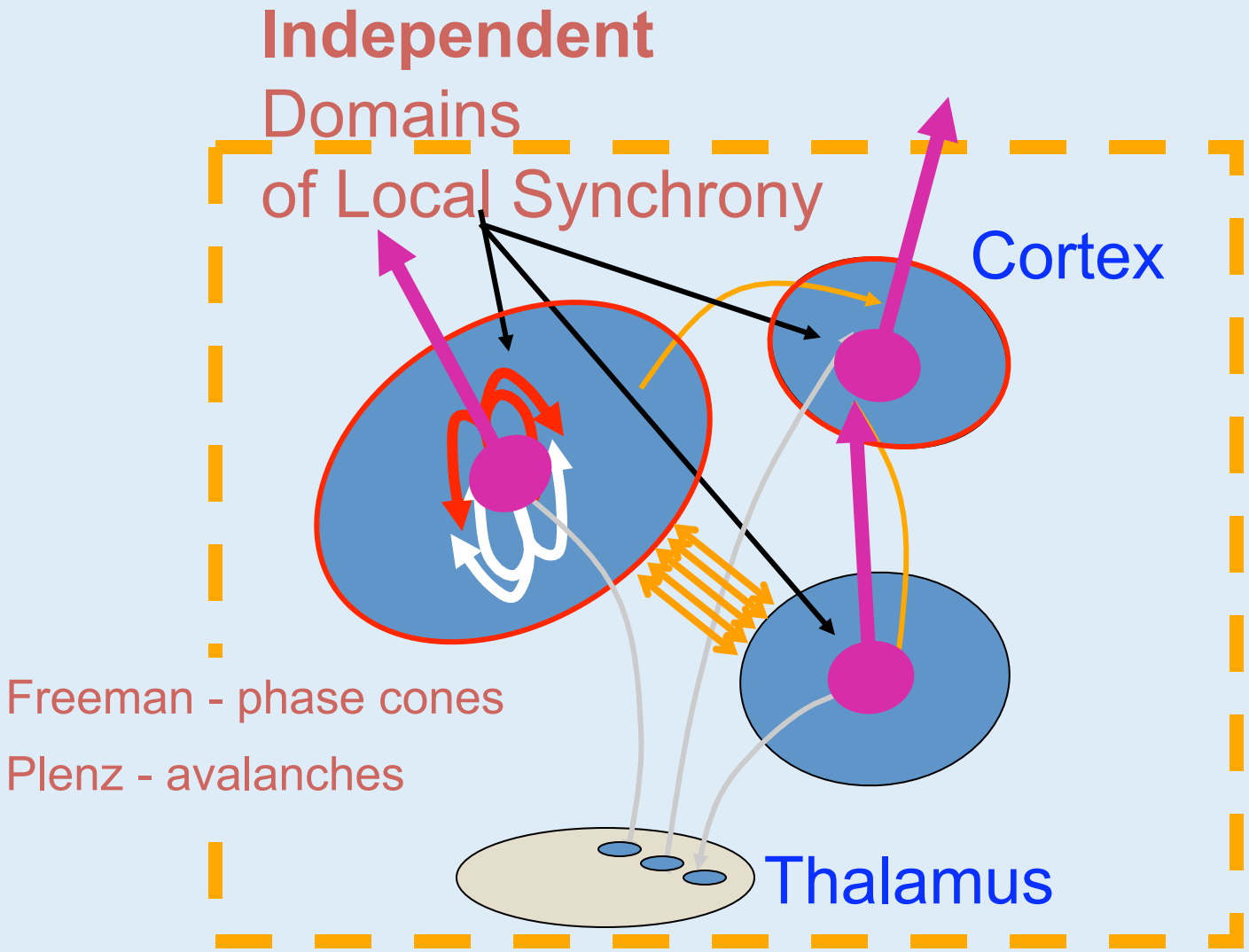

Independent Component Analysis of Electroencephalographic Data

Abstract

Infomax ICA

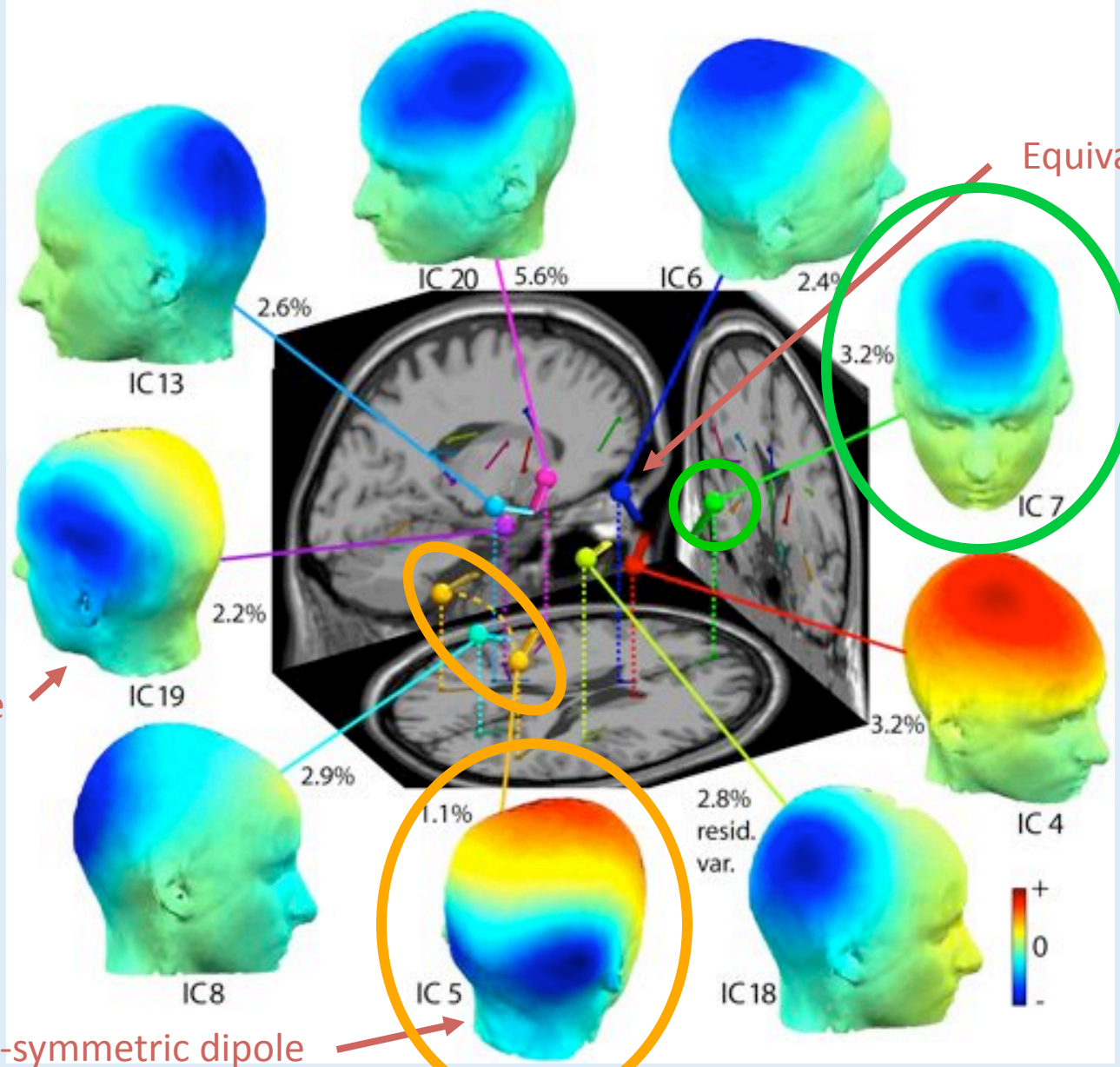
Makeig et al., NIPS95

Are EEG source outputs (nearly) independent?



S. Makeig (2007)

Independent brain EEG sources



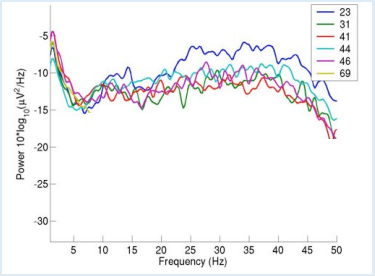
Equivalent dipoles

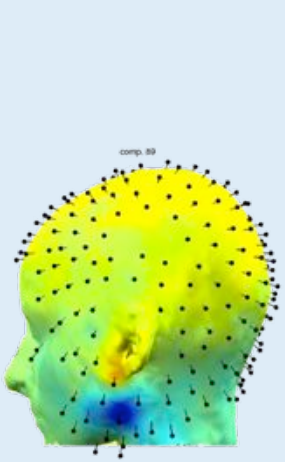
Single dipole source

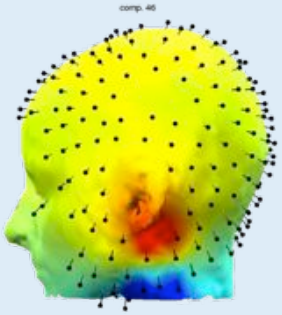
Dual-symmetric dipole source

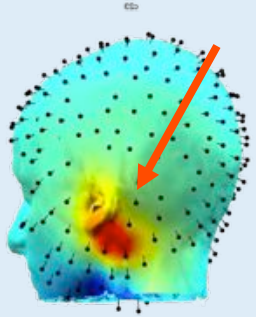
Julie Onton & S. Makeig (2006)

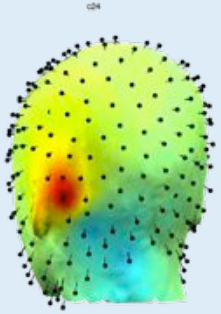
Independent muscle signals

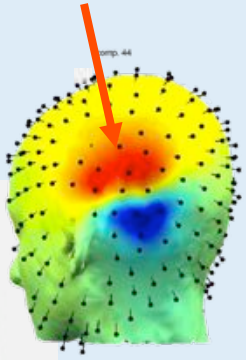


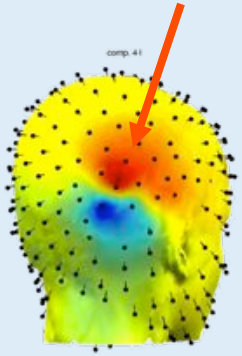


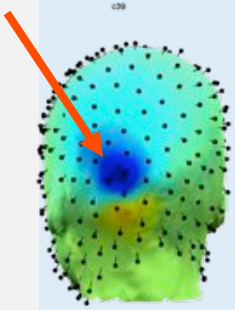


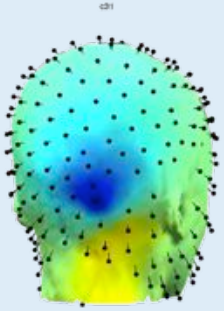


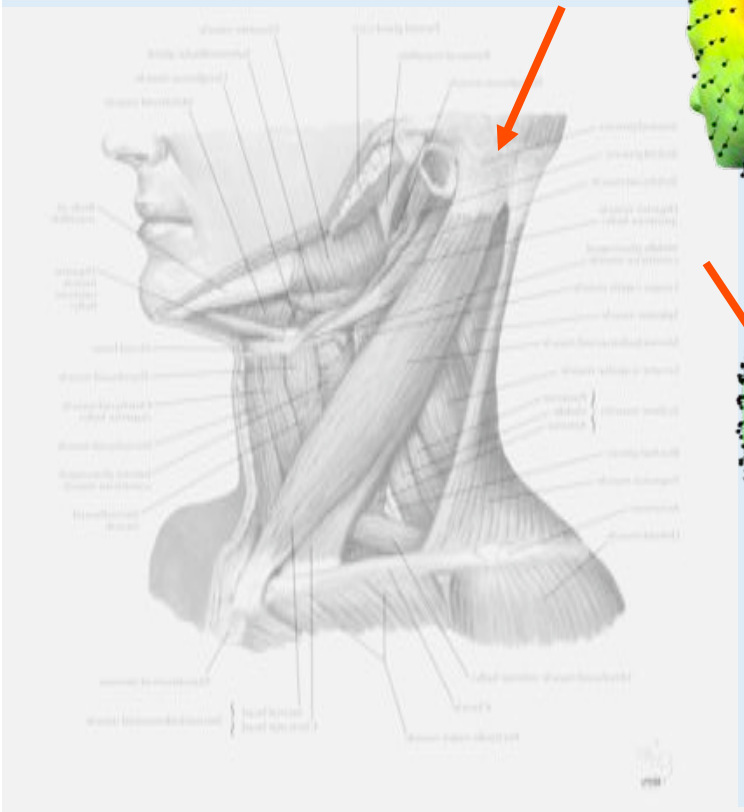


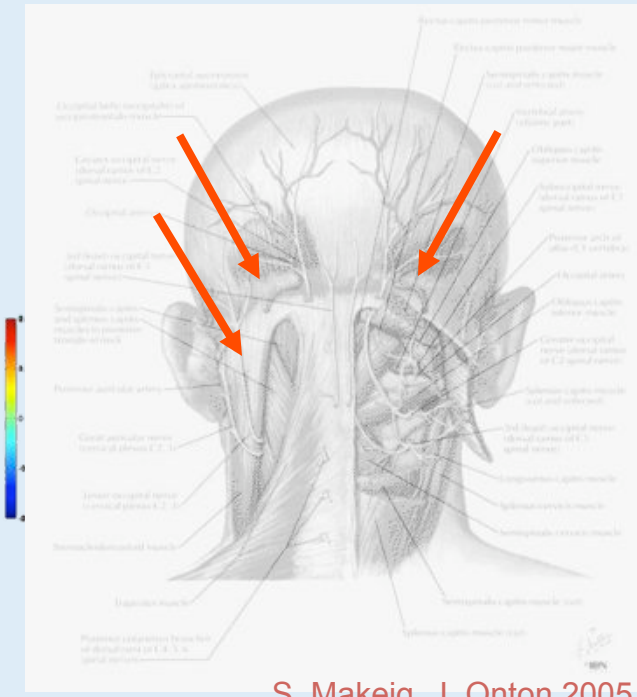






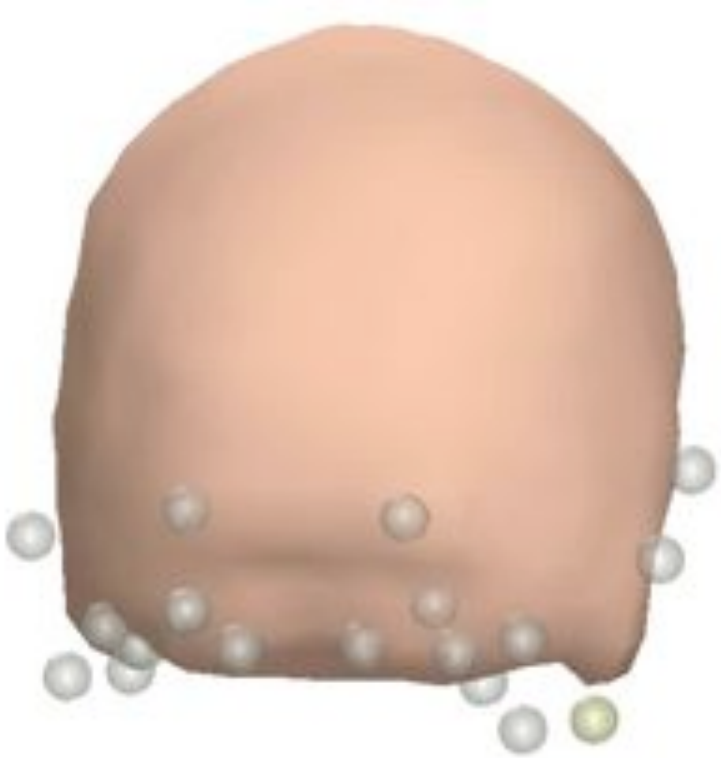


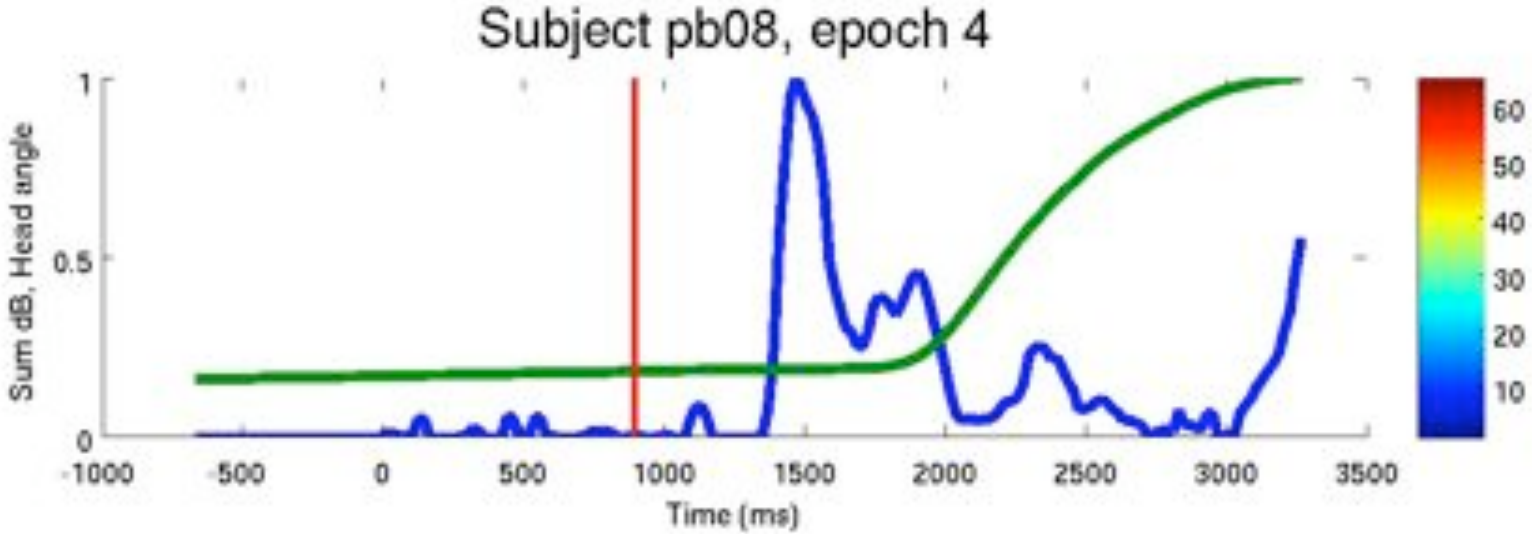




S. Makeig, J. Onton 2005

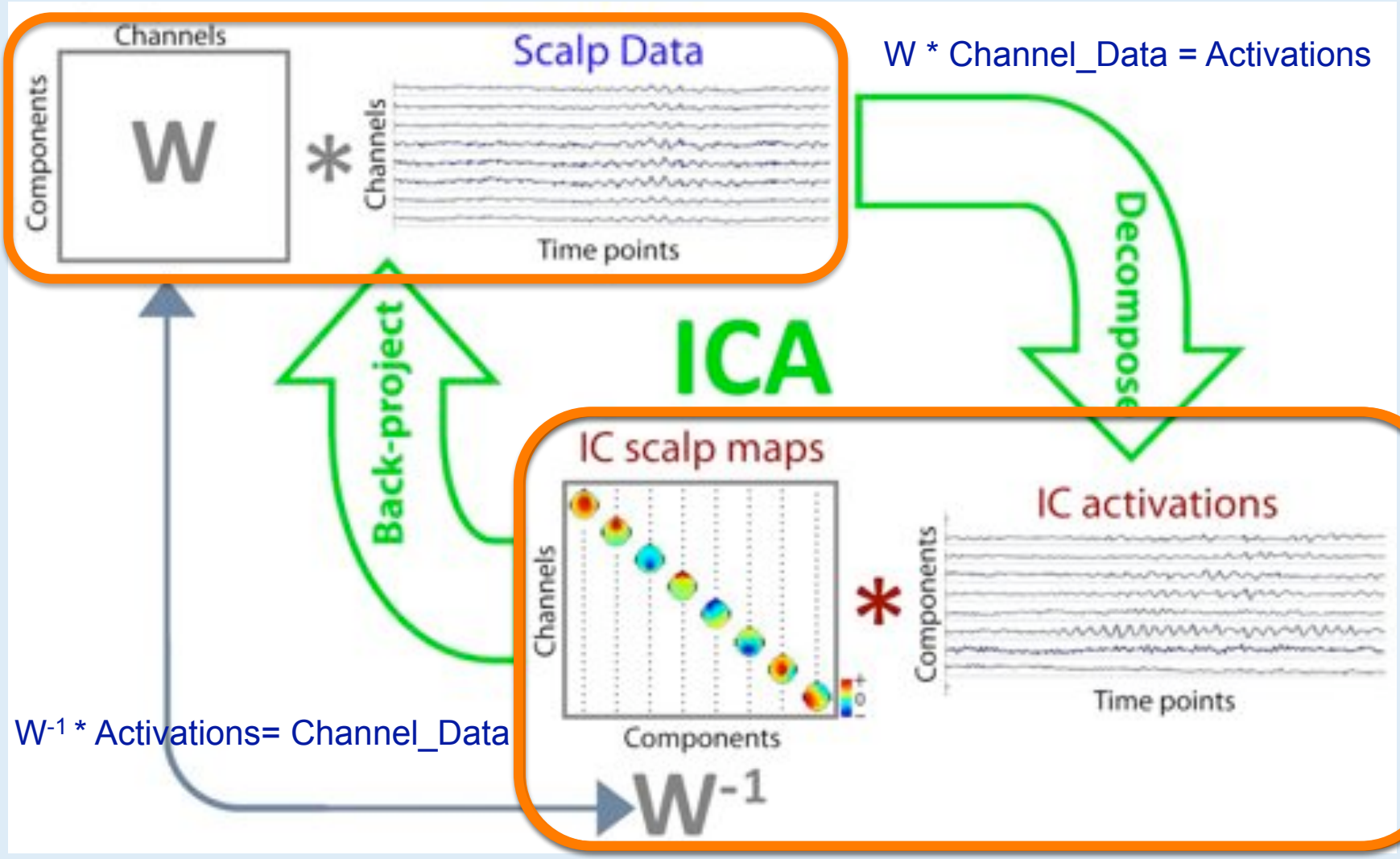
Distributed muscle / movement events



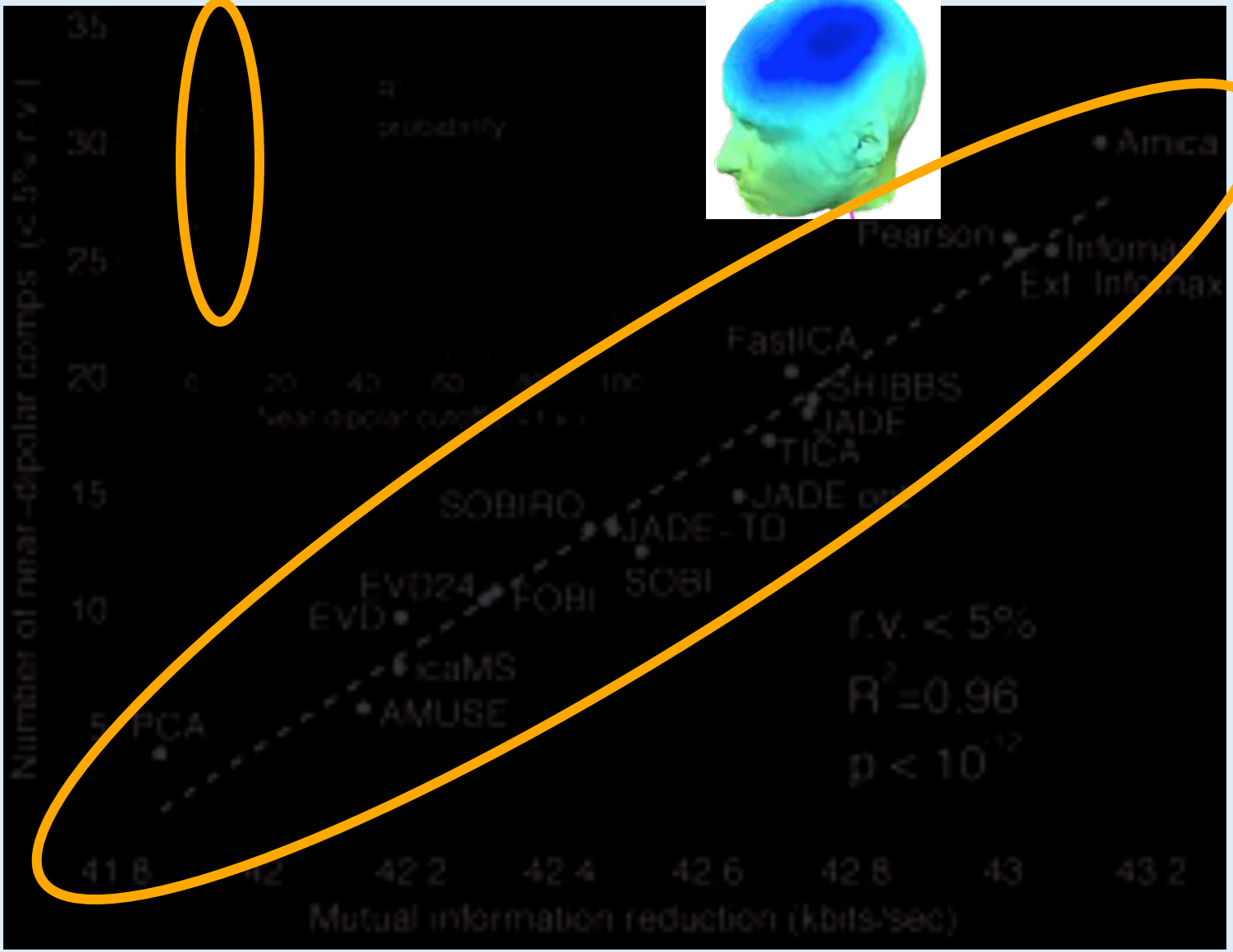


N. BigdelyS. Makeig, 2009

ICA is a linear data decomposition method

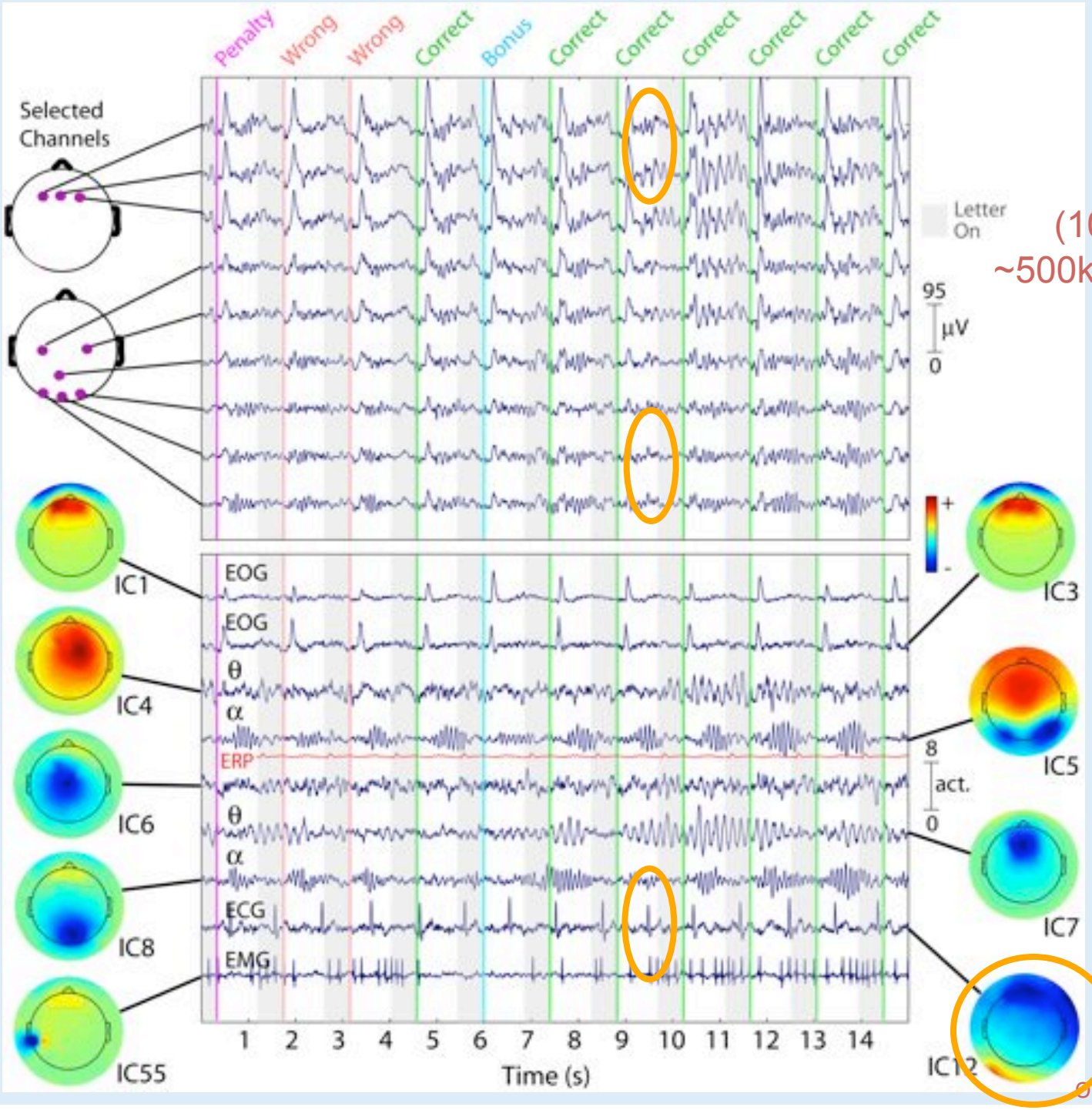


Independent Components of Human EEG are Dipolar



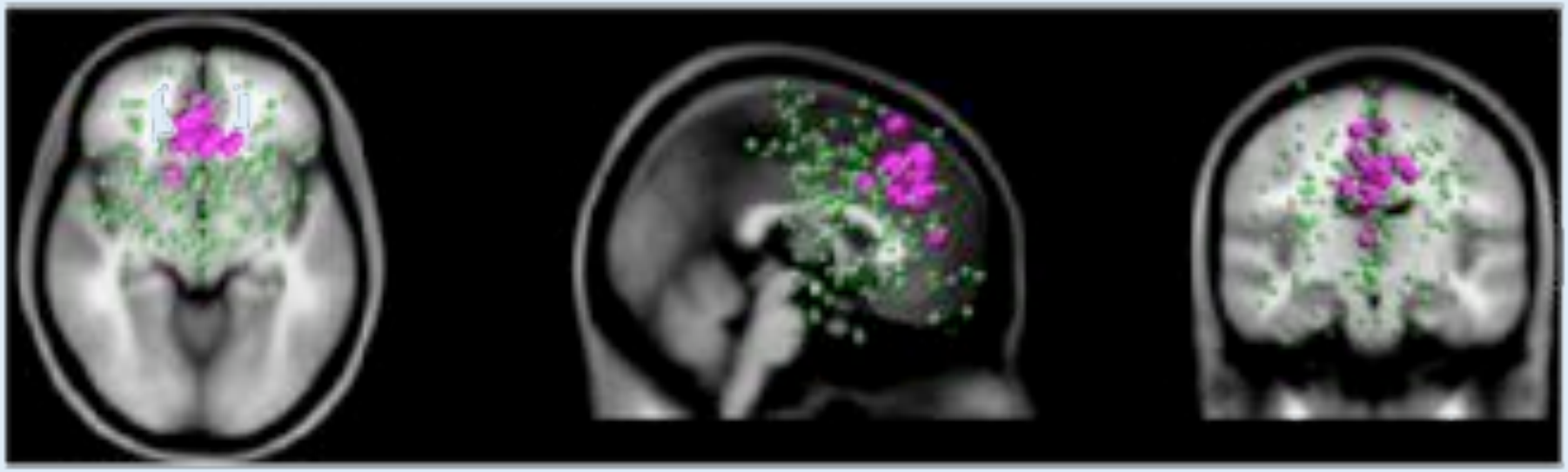
ICA in practice

(100 channels, ~500k time points)



Onton & Makeig, 2006

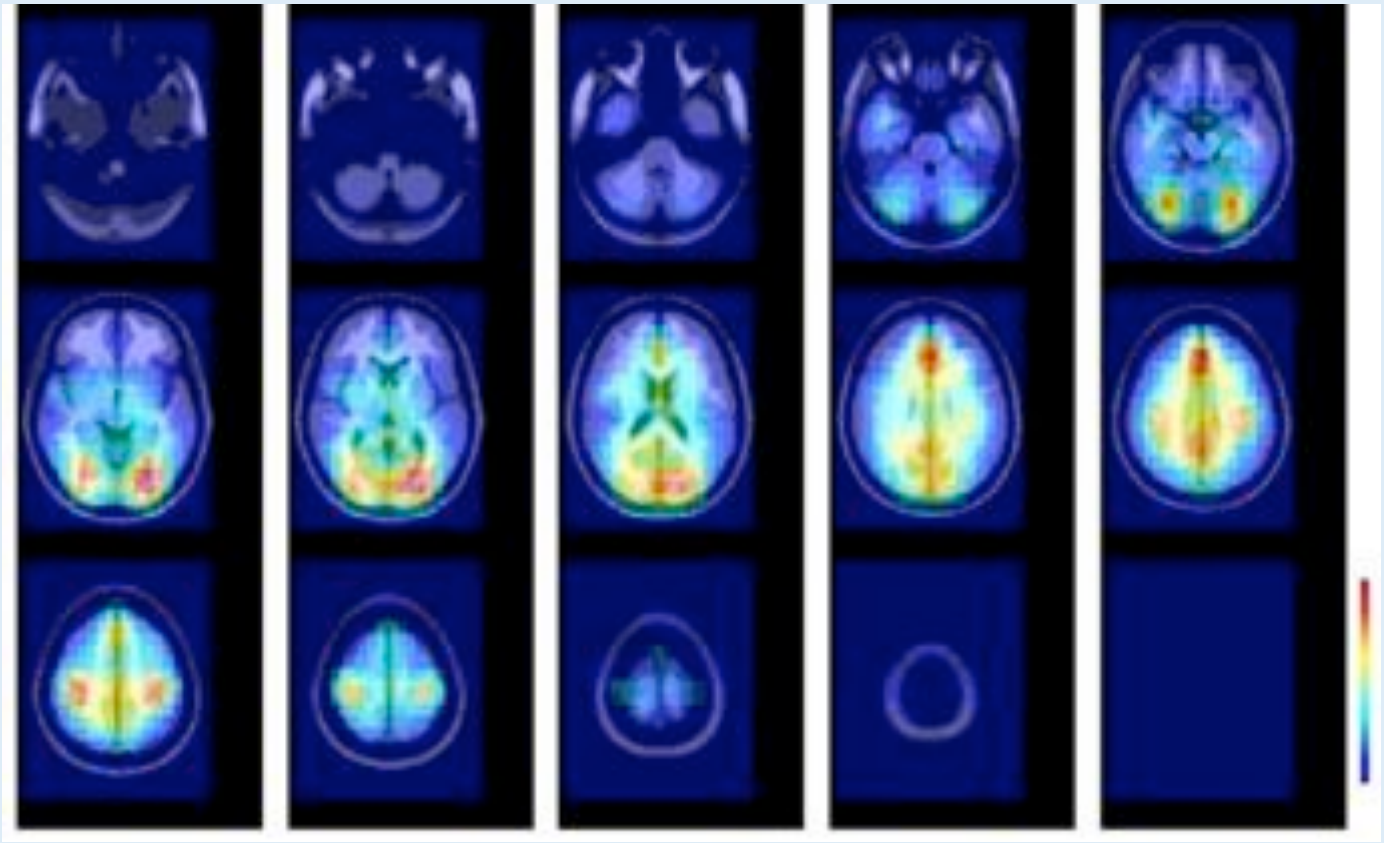
24 Subjects –Frontal Midline Theta Sources



Onton & Makeig 2006

Equivalent dipole density

Visual Working Memory



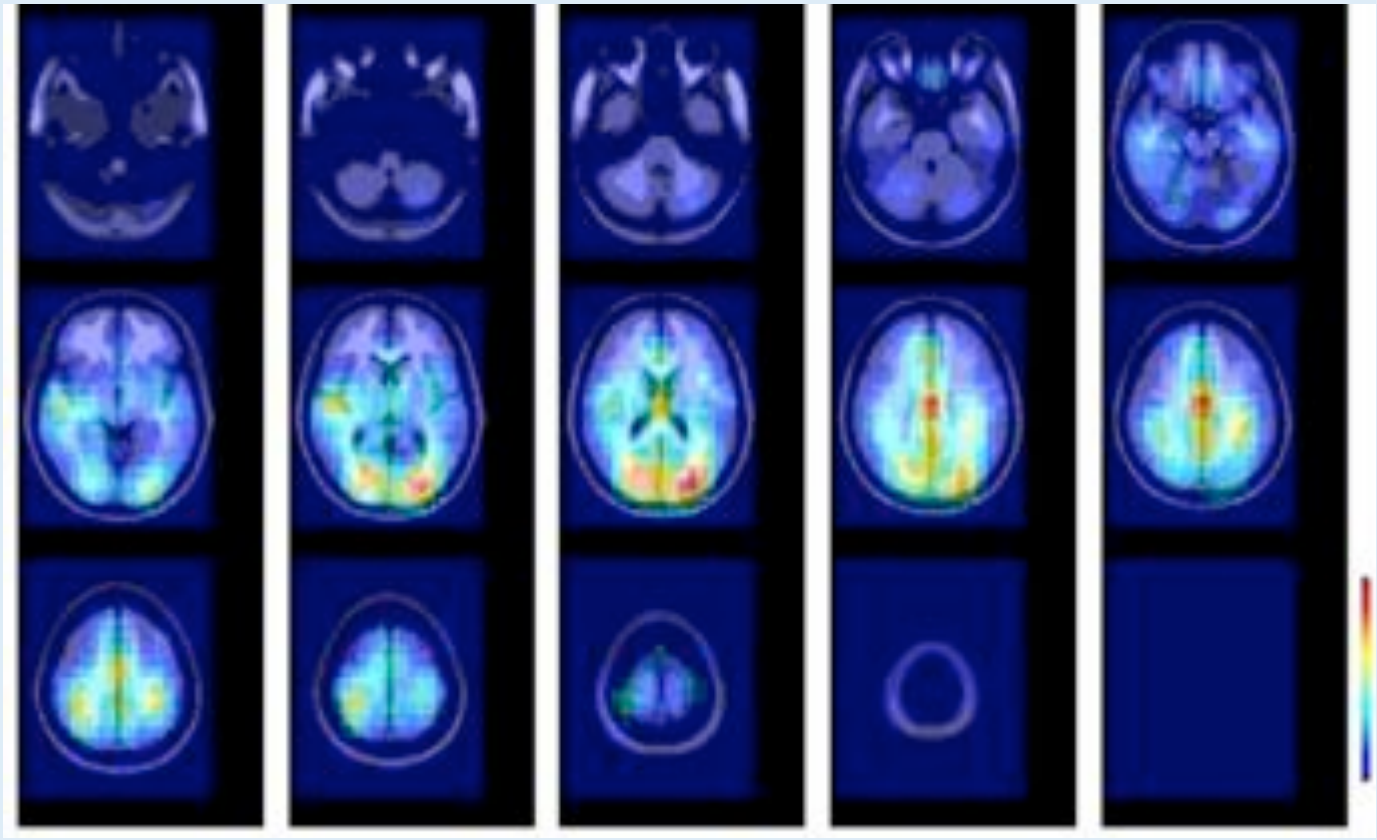
Sternberg letter memory task

Onton et al., 2005

Onton et al., ‘05

Equivalent dipole density

Auditory Novelty



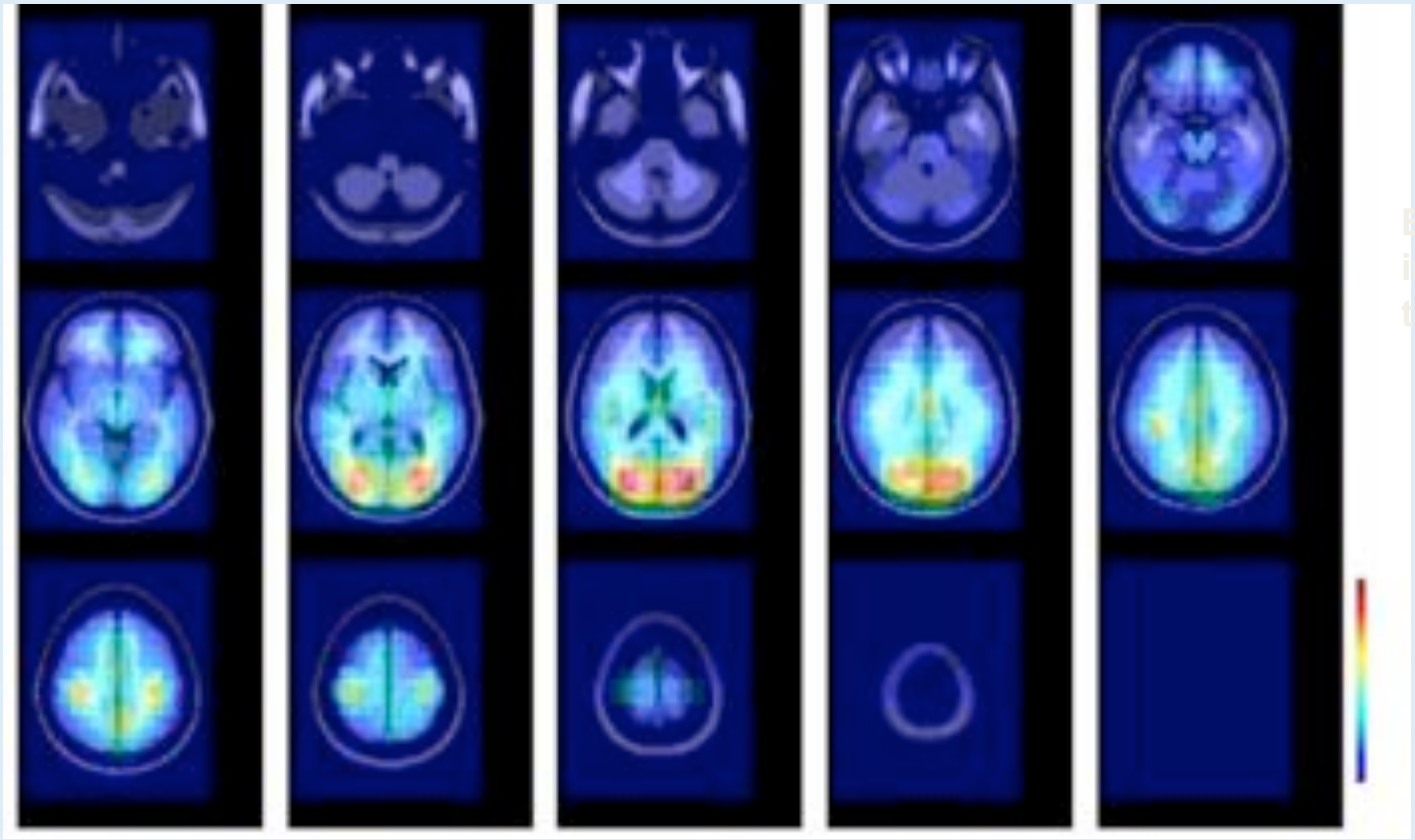
Auditory oddball plus novel sounds

Onton et al., 2005

Onton et al., ‘05

Equivalent dipole density

Emotion Imagination

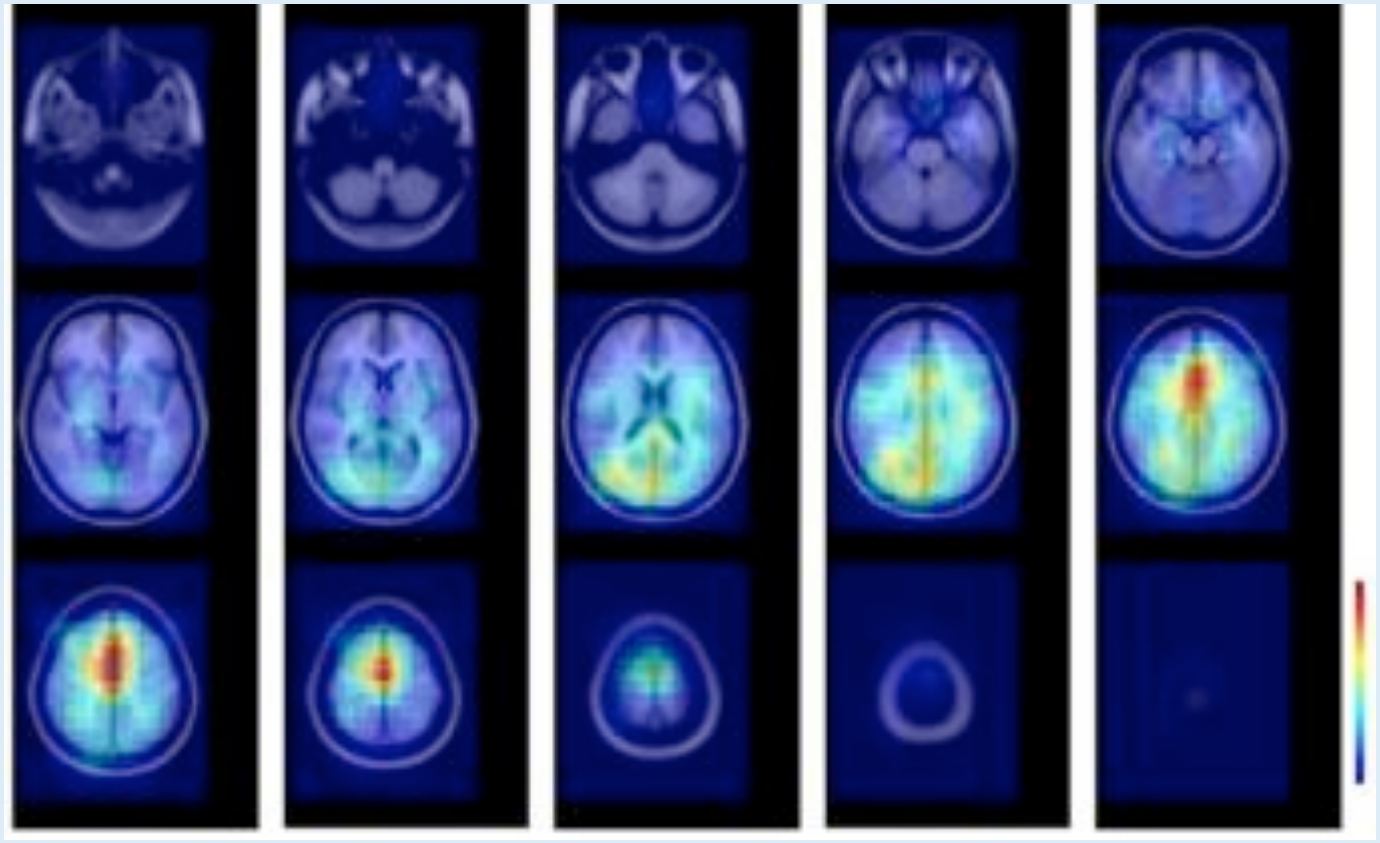


Onton et al., 2005

Onton et al., ‘05

Equivalent dipole density

Task A – Old/New Word Memory



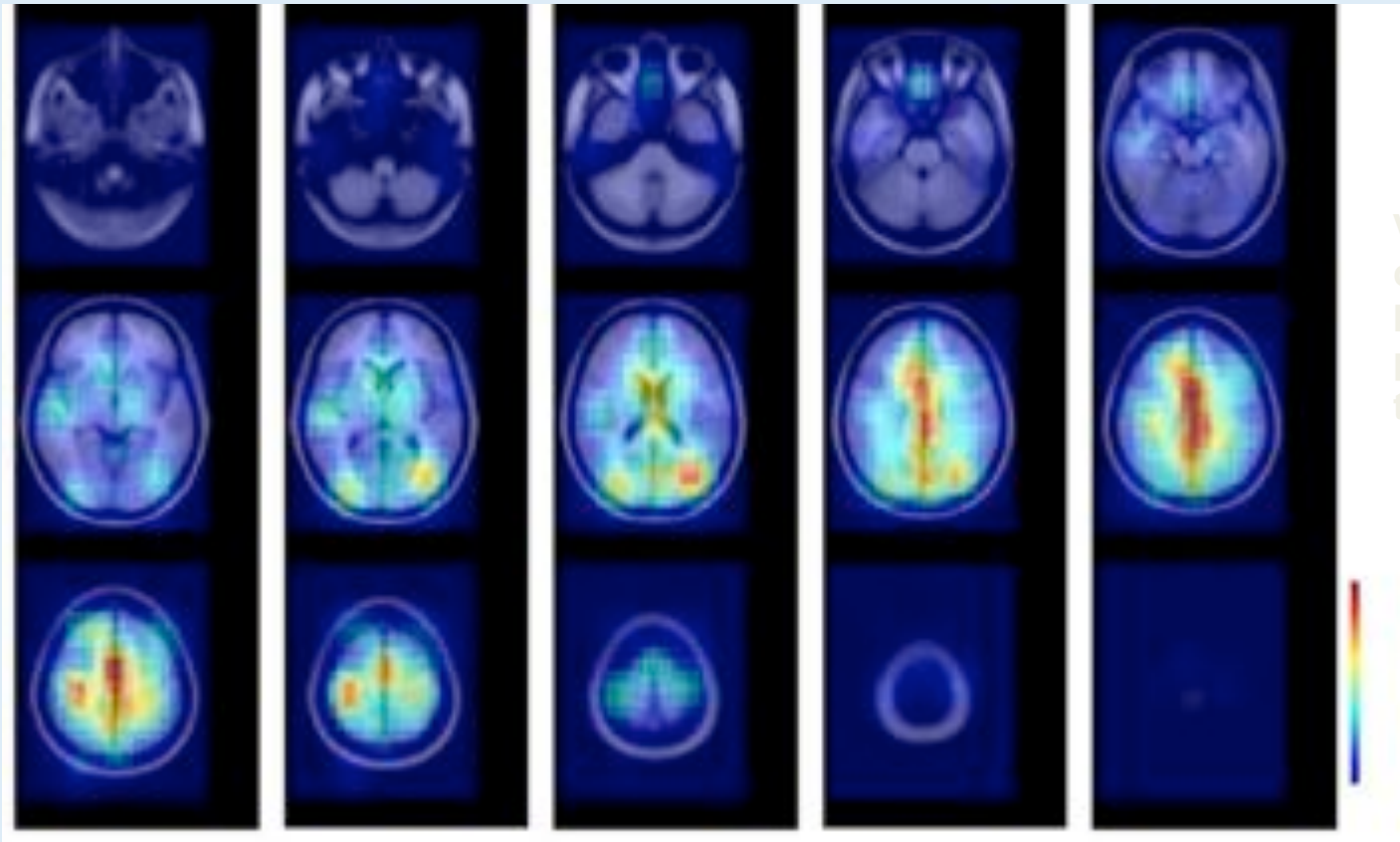
dipoledensity()

Onton et al., 2005

Onton et al., ‘05

Equivalent dipole density

Task B – Cued finger movements



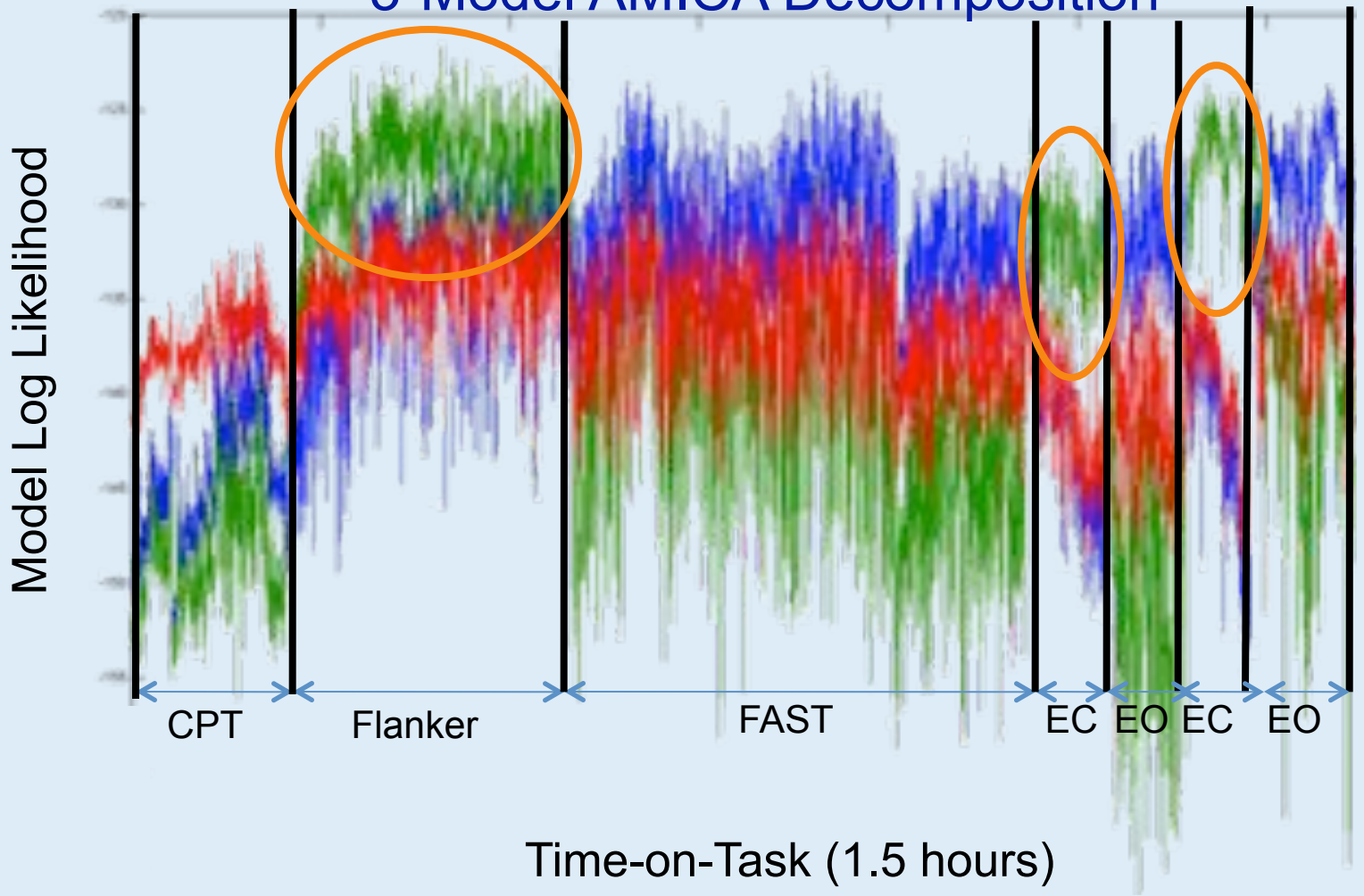
dipoledensity()

Onton et al., 2005

Onton et al., ‘05

Modeling Spatiotemporal Variability

3-Model AMICA Decomposition



Grainne MacLoughlin & Jason Palmer, 2010

Mining Event-Related Brain Dynamics

1. Consider, in so far as possible, the multi-dimensional dynamics of the brain as expressed in the whole recorded signal.
2. Un-mix source (and artifact) contributions of individual source areas using independent component analysis (ICA).
3. Visualize trial-by-trial *relationships* of source component activities to experimental variables (using 2-D 'ERP image' plots).
4. Model the event-related dynamics of the source components (using time/frequency analysis).
5. Localize the separated source areas using biophysical inverse modeling.
6. Compare similarities in source dynamics and locations across subjects using cluster analysis.
7. Model transient source network dynamics and the contexts in which they appear.

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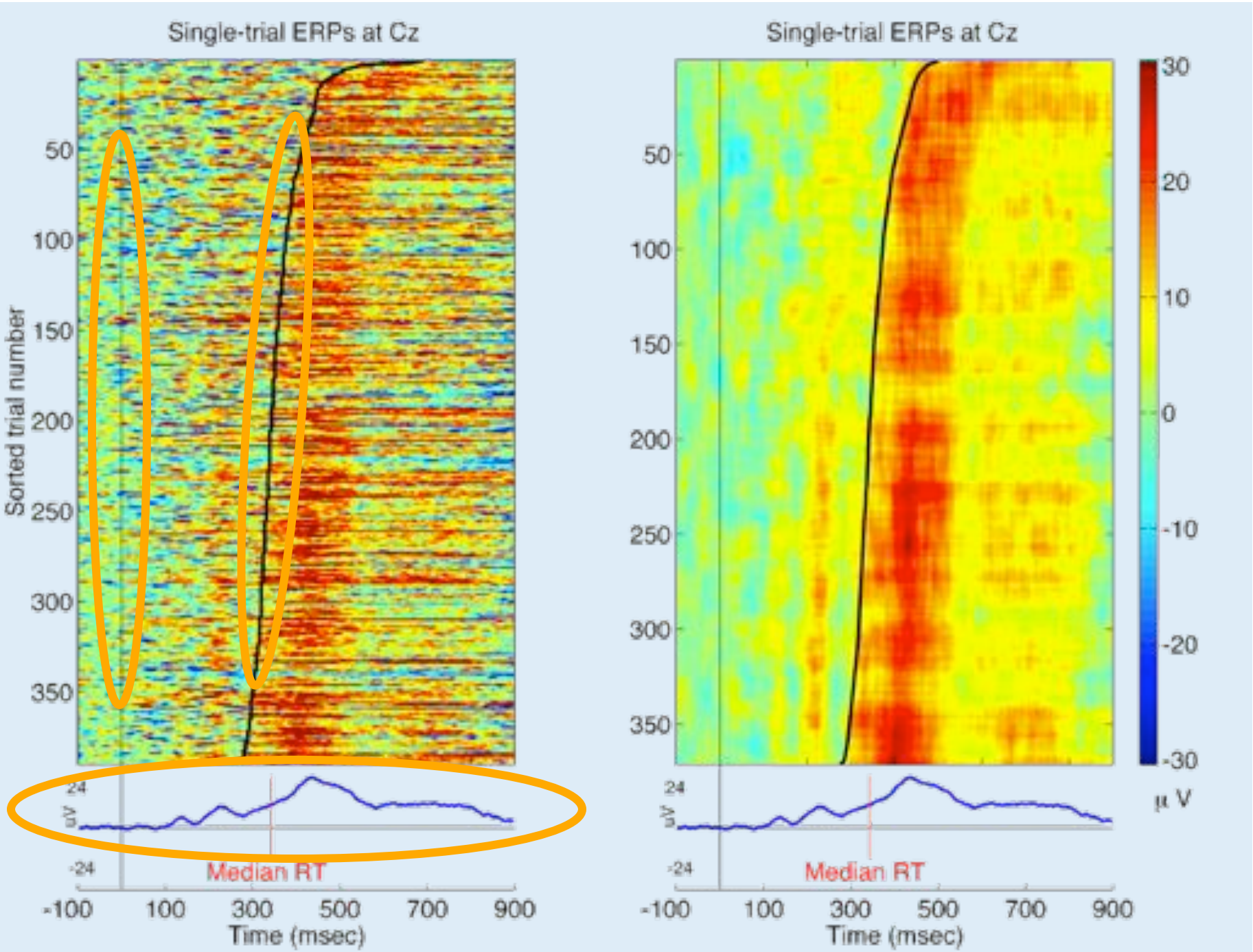
EEGLAB Concepts / Measures

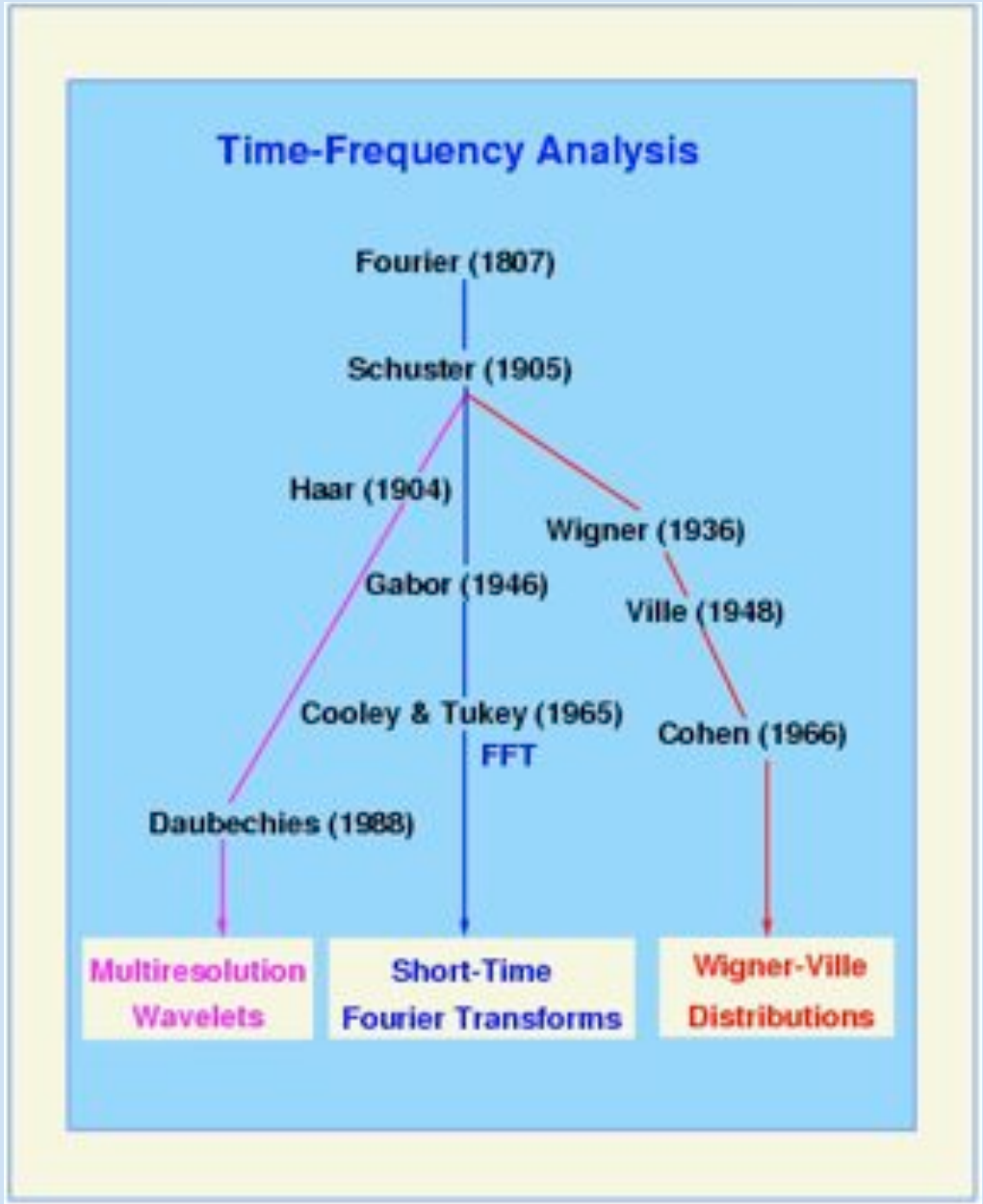
- ERSP – event-related spectral power
- ITC – inter-trial coherence (phase locking)
- ERC – event-related coherence

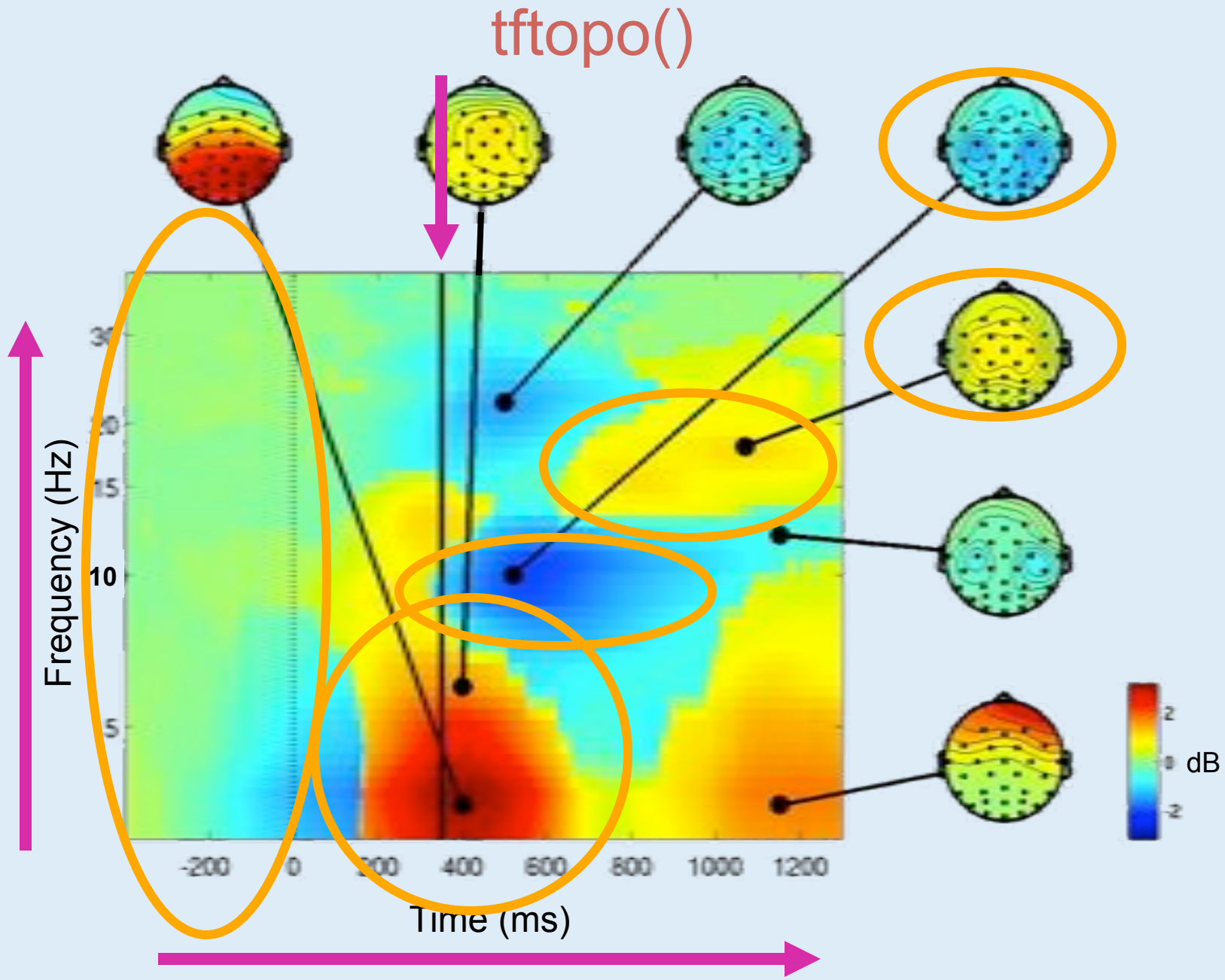
EEGLAB Measures / Visualizations

- erpimage() – sorted trial-by-trial dynamics
- envtopo() – ERPs and components
- tftopo() – event-related spectral power changes



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


Time-Frequency Analysis
Fourier (1807)
Schuster (1905)
Haar (1904)
Wigner (1936)
Gabor (1946)
Ville (1948)
Cooley & Tukey (1965)
FFT
Cohen (1966)
Daubechies (1988)
Multiresolution
Wavelets
Short-Time
Fourier Transforms
Wigner-Ville
Distributions

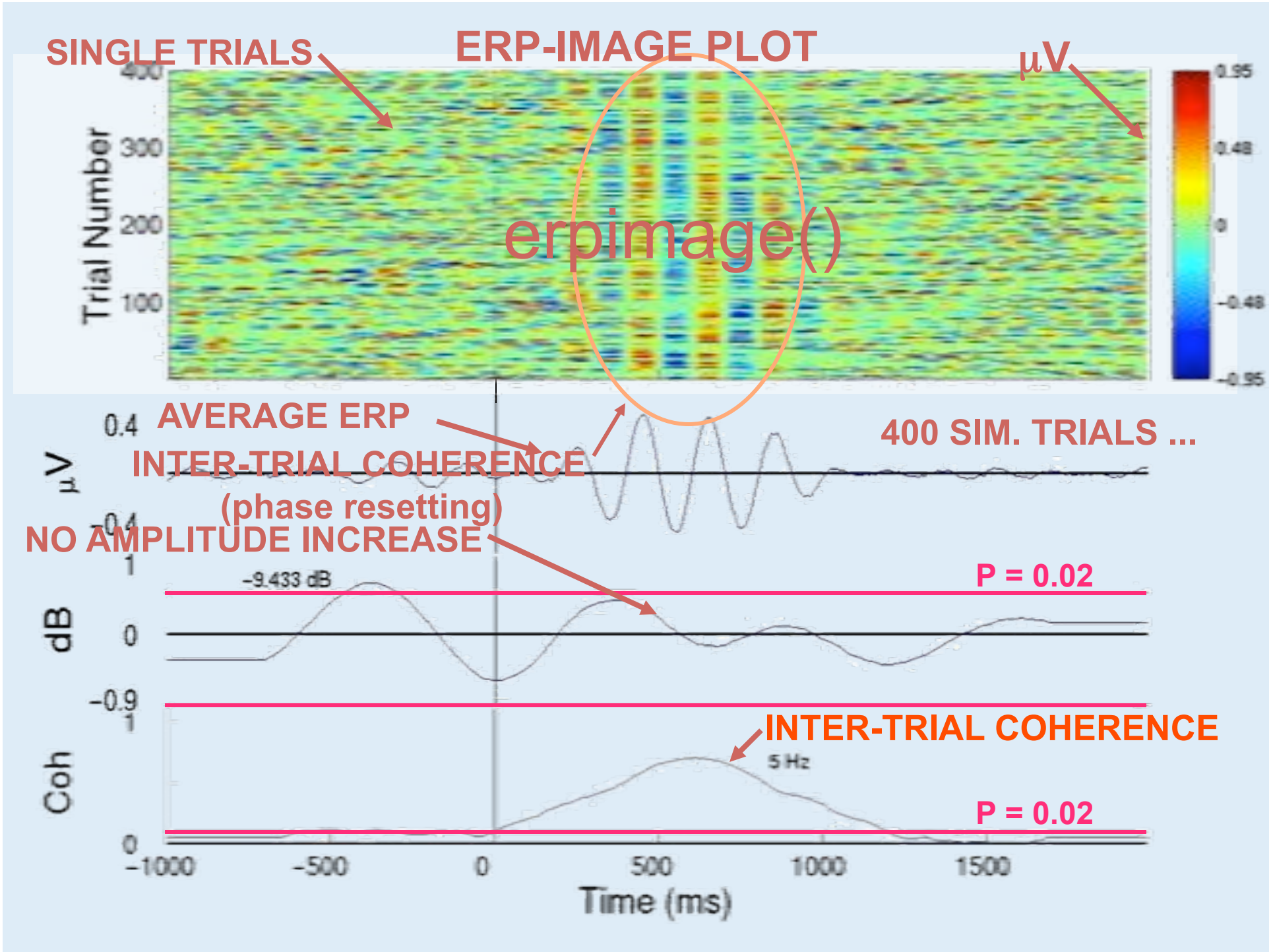


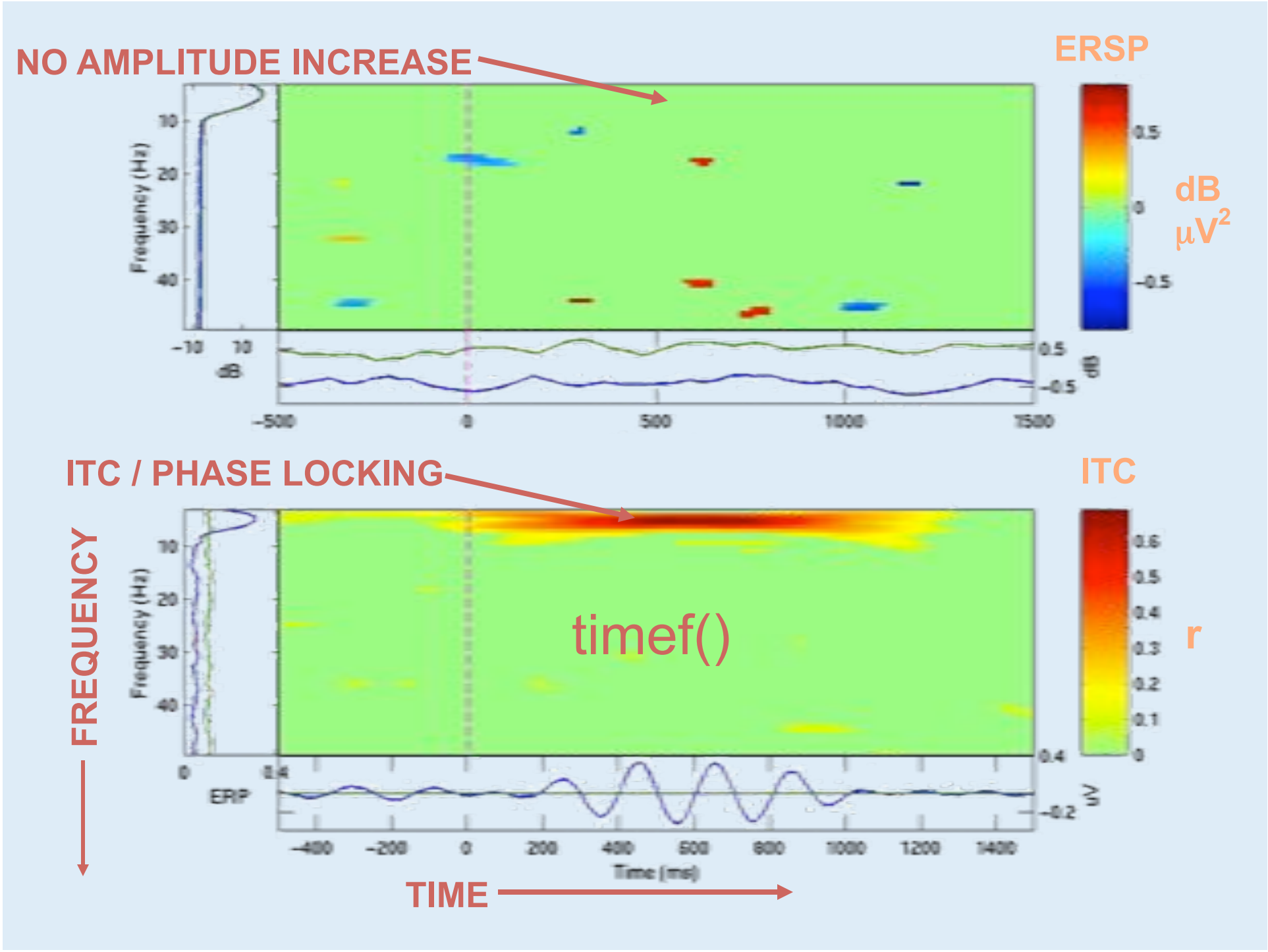
Makeig et al., *PLOS* '04

Inter-trial Coherence (ITC)

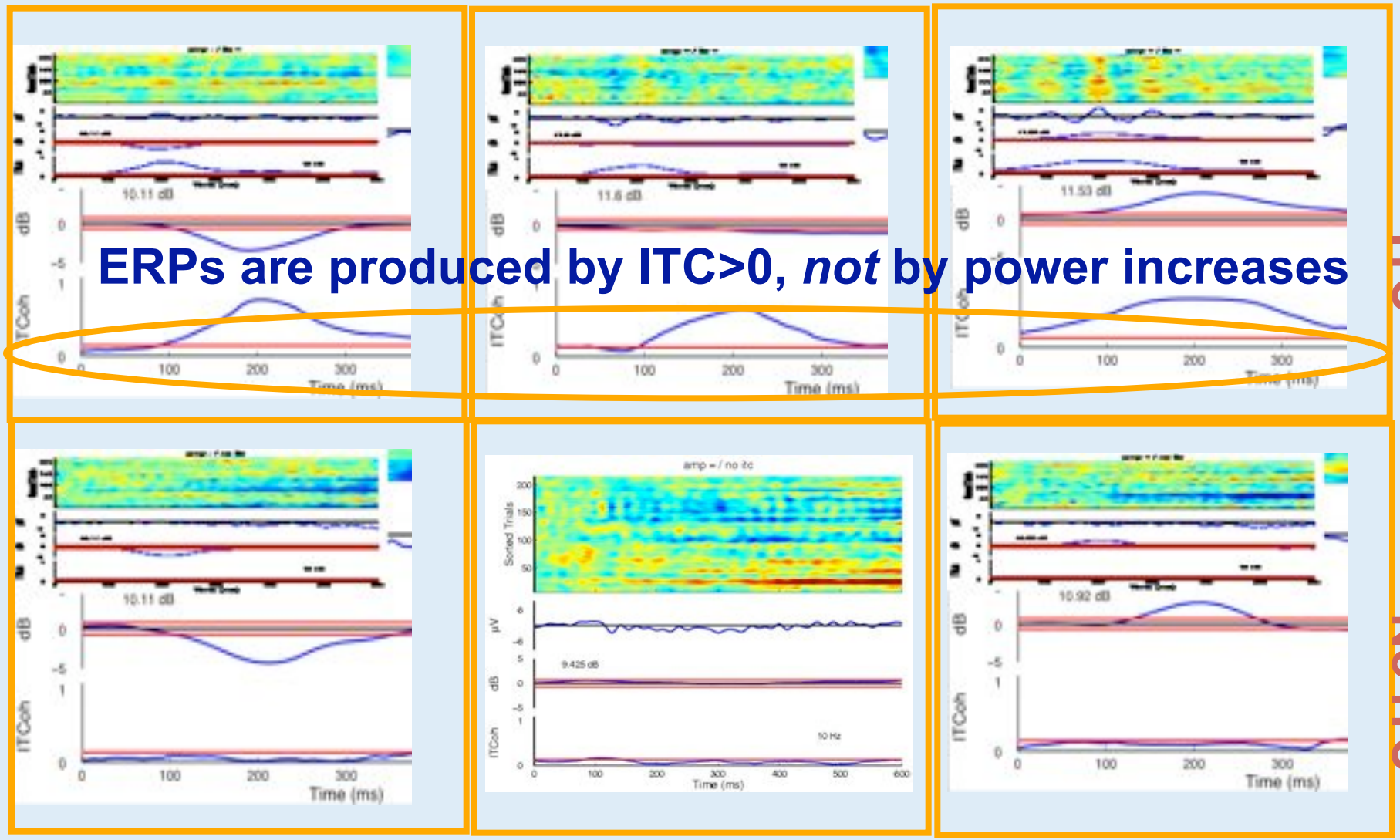
("phase-locking factor")

- Significant consistency of local phase of a physiological waveform across successive trials.

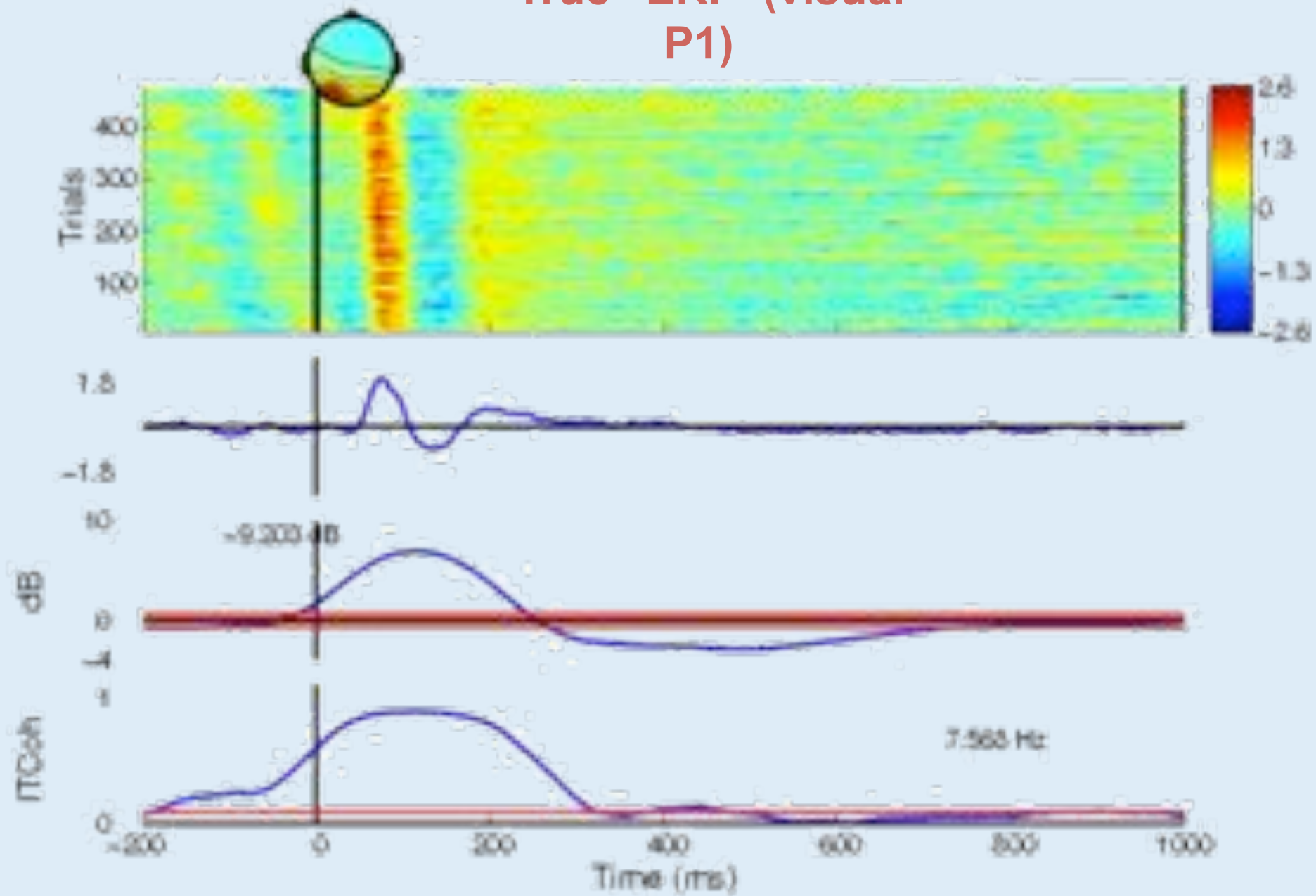

SINGLE TRIALS
ERP-IMAGE PLOT
μV
erpimage()
Trial Number
400
300
200
100
0.95
0.48
0
-0.48
-0.95
AVERAGE ERP
INTER-TRIAL COHERENCE
(phase resetting)
NO AMPLITUDE INCREASE
400 SIM. TRIALS ...
μV
0.4
-0.4
dB
-9.433 dB
1
0
-0.9
P = 0.02
Coh
INTER-TRIAL COHERENCE
5 Hz
P = 0.02
1
0
-1000
-500
0
500
1000
1500
Time (ms)

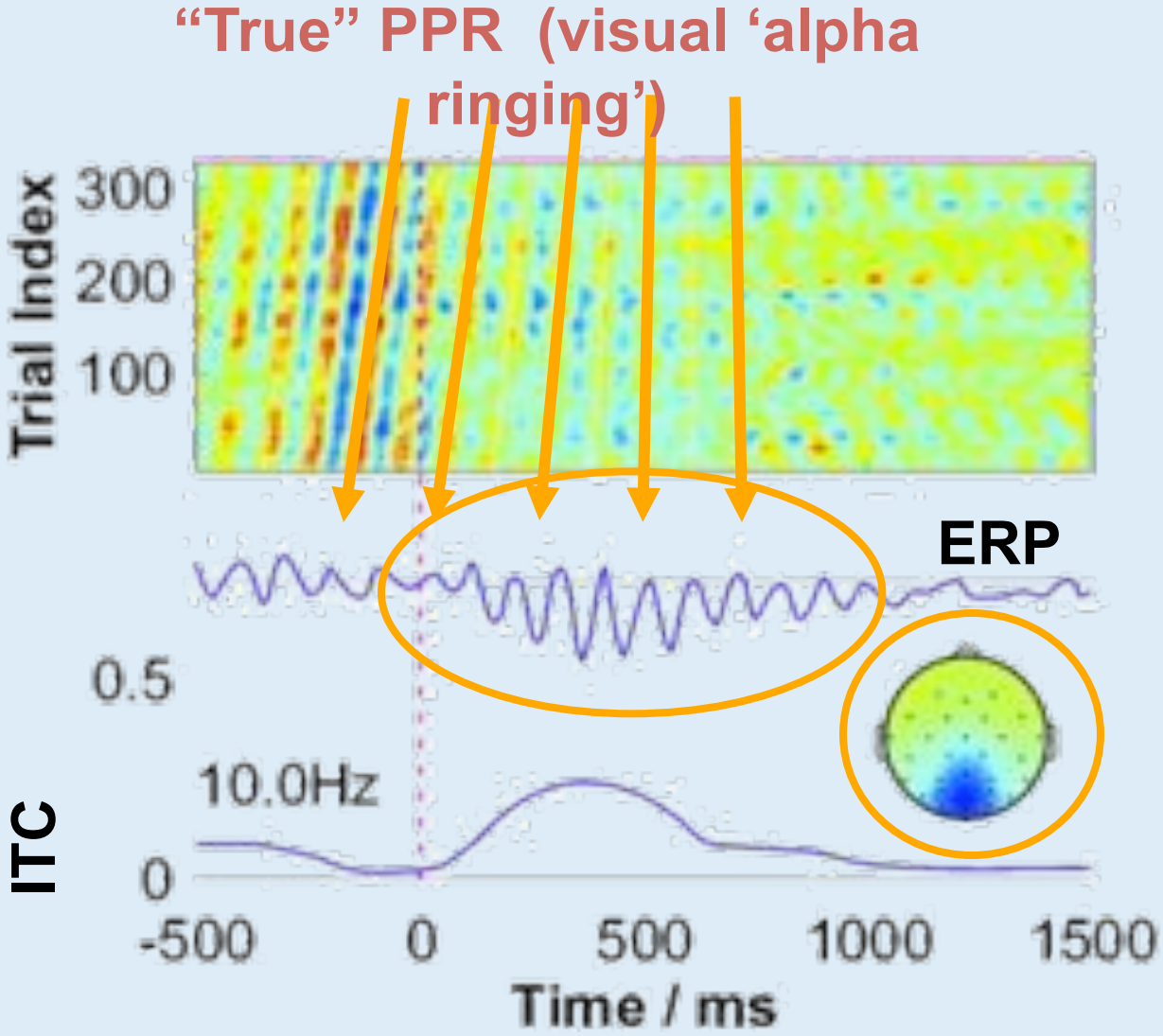

NO AMPLITUDE INCREASE
ERSP
dB
μV^2
Frequency (Hz)
ITC / PHASE LOCKING
ITC
r
timef()
FREQUENCY
TIME
ERP
Time (ms)

Space of time / frequency changes …



“True” ERP (visual P1)

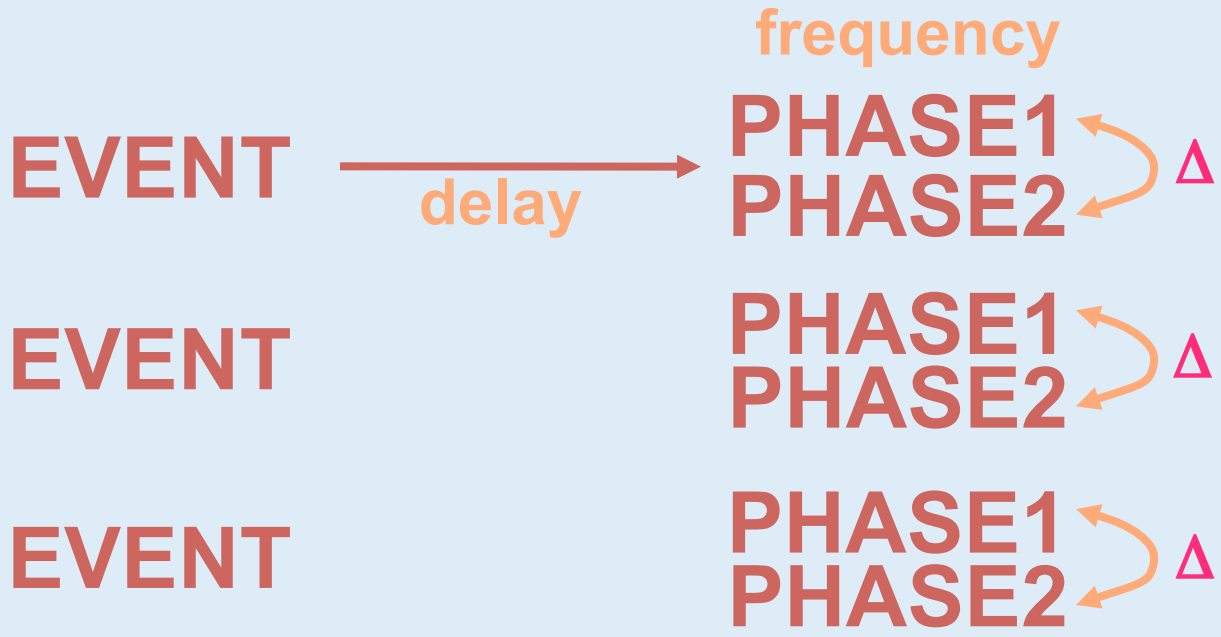



"True" PPR (visual 'alpha ringing')
Trial Index
300
200
100
ERP
0.5
10.0Hz
ITC
0
-500
0
500
1000
1500
Time / ms

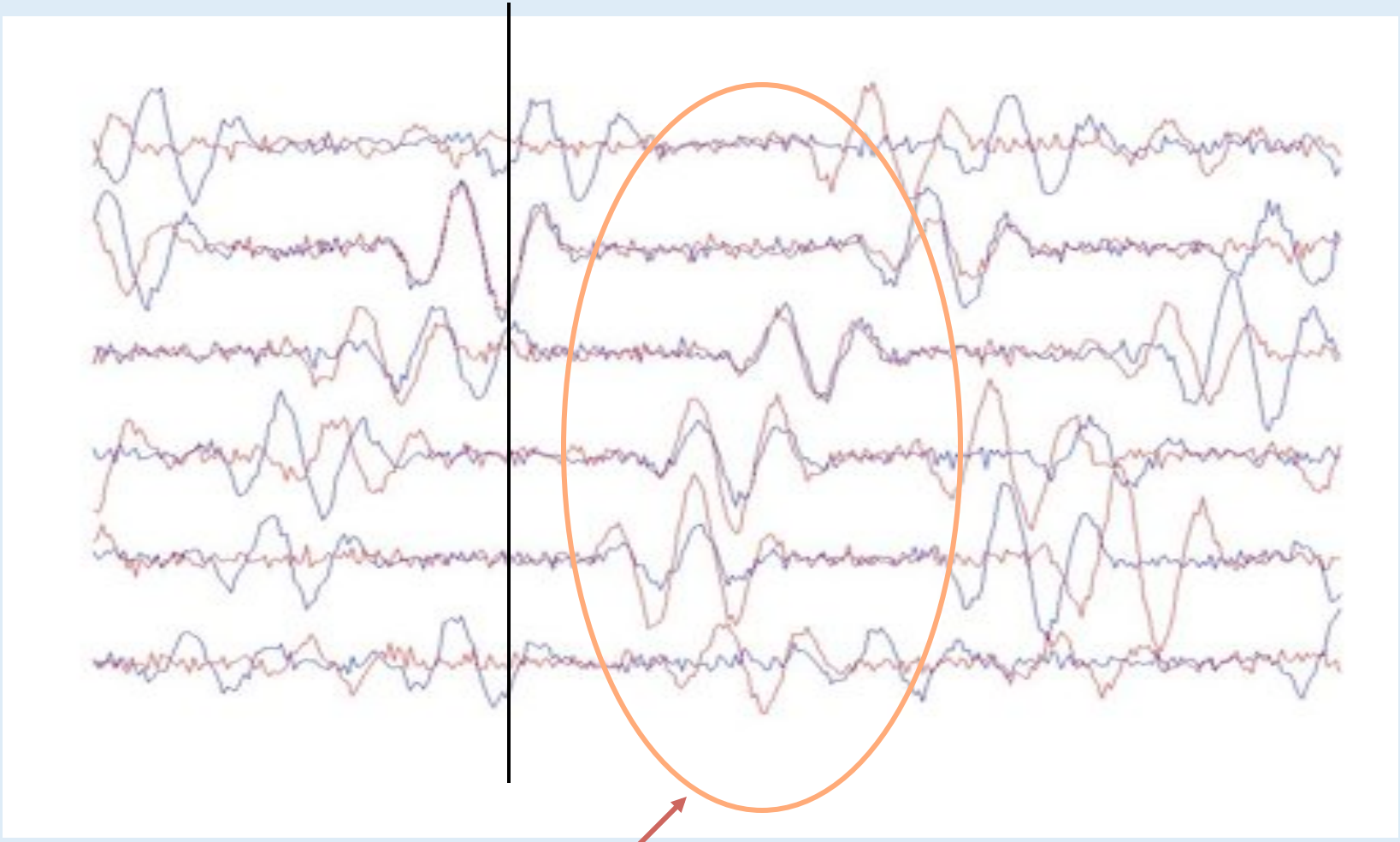
S. Enghoff

Event-Related Coherence (ERC)

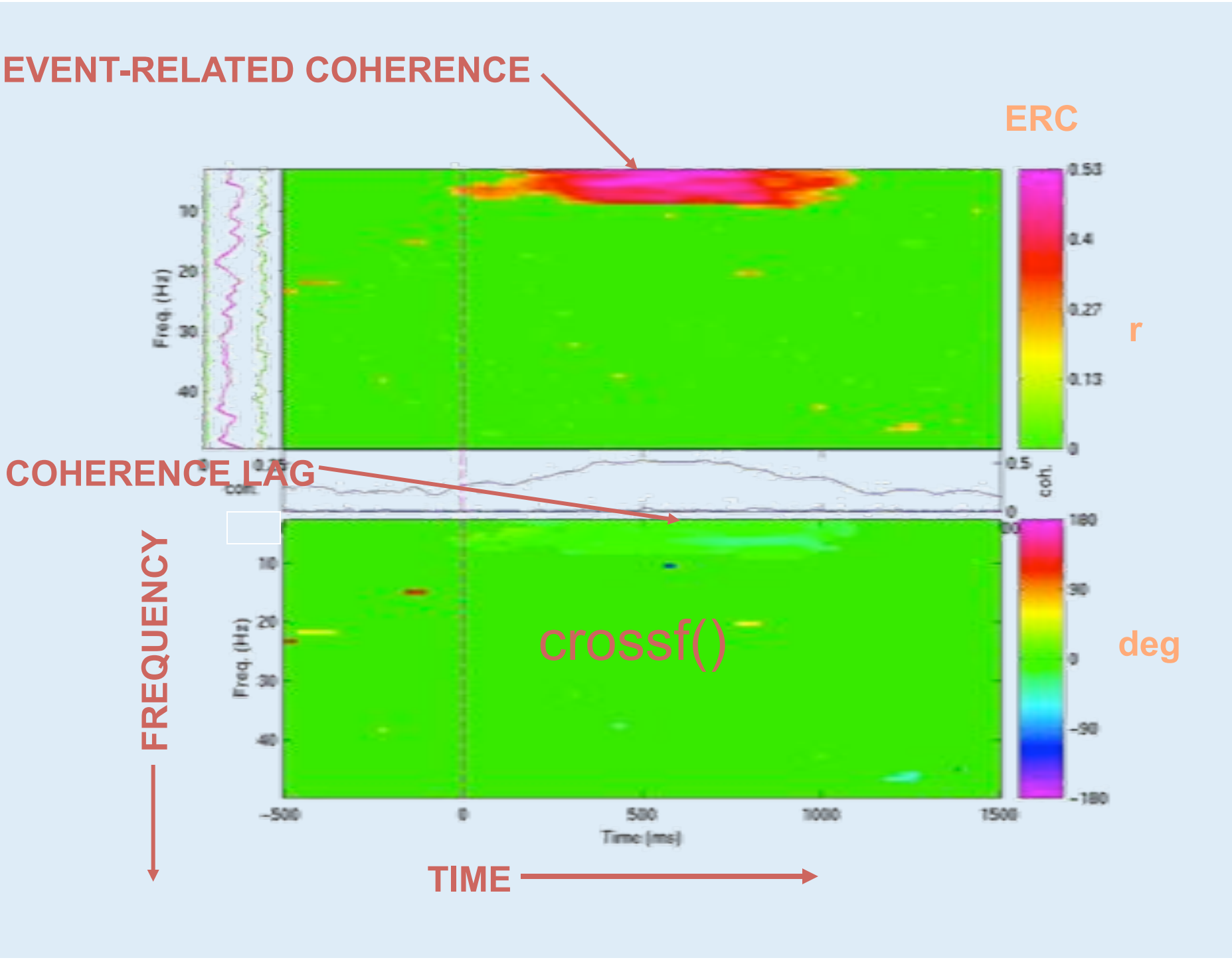
• **Significant consistency of local phase difference between two concurrent physiological waveforms.**



TWO SIMULATED THETA PROCESSES



Event-related Coherence


EVENT-RELATED COHERENCE
ERC
r
COHERENCE LAG
coh.
crossf()
deg
FREQUENCY
TIME
Freq. (Hz)
Time (ms)
-500
0
500
1000
1500
10
20
30
40
0.53
0.4
0.27
0.13
0
-0.5
180
90
-90
-180

Fusiform

10-Hz Coh.

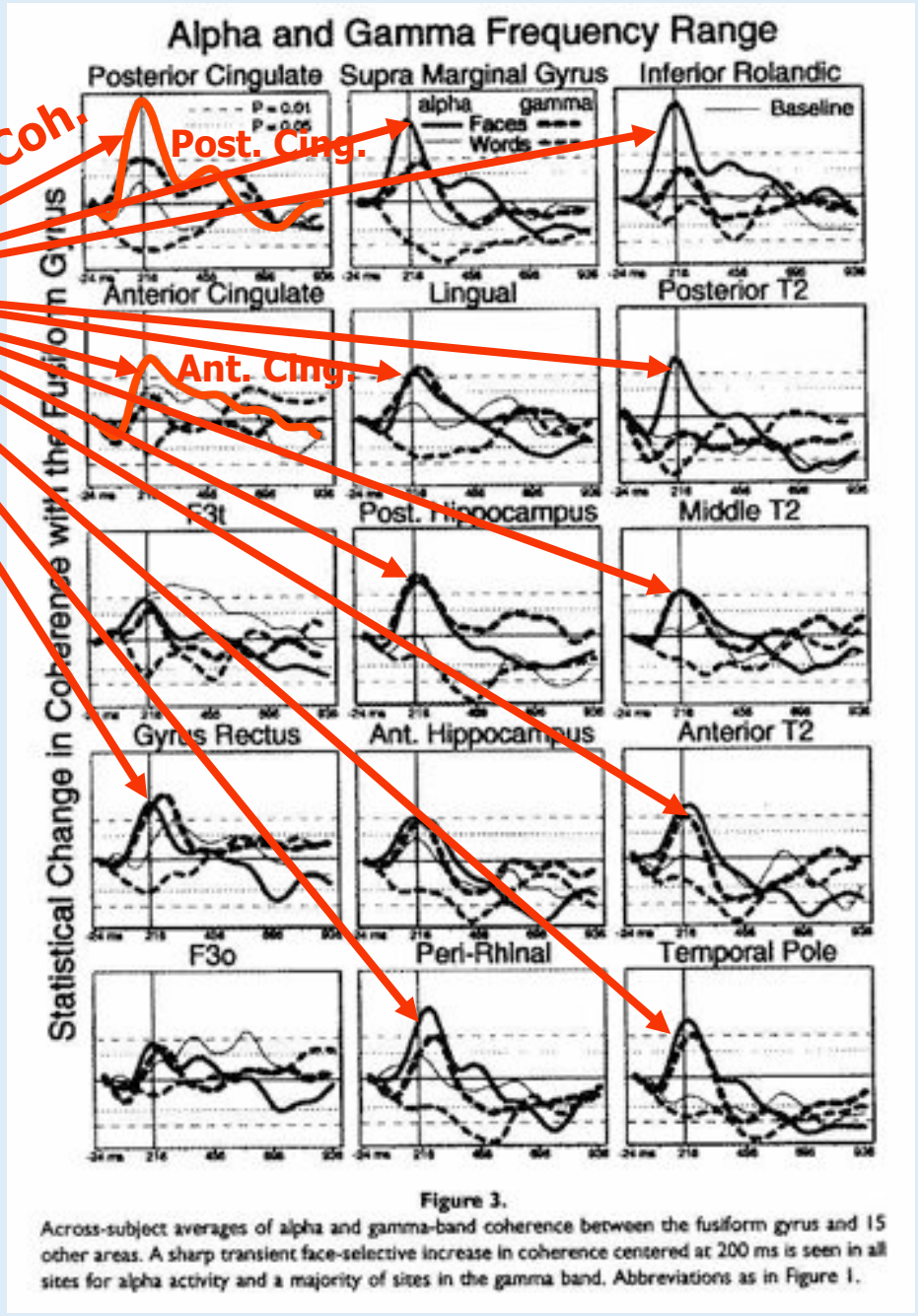
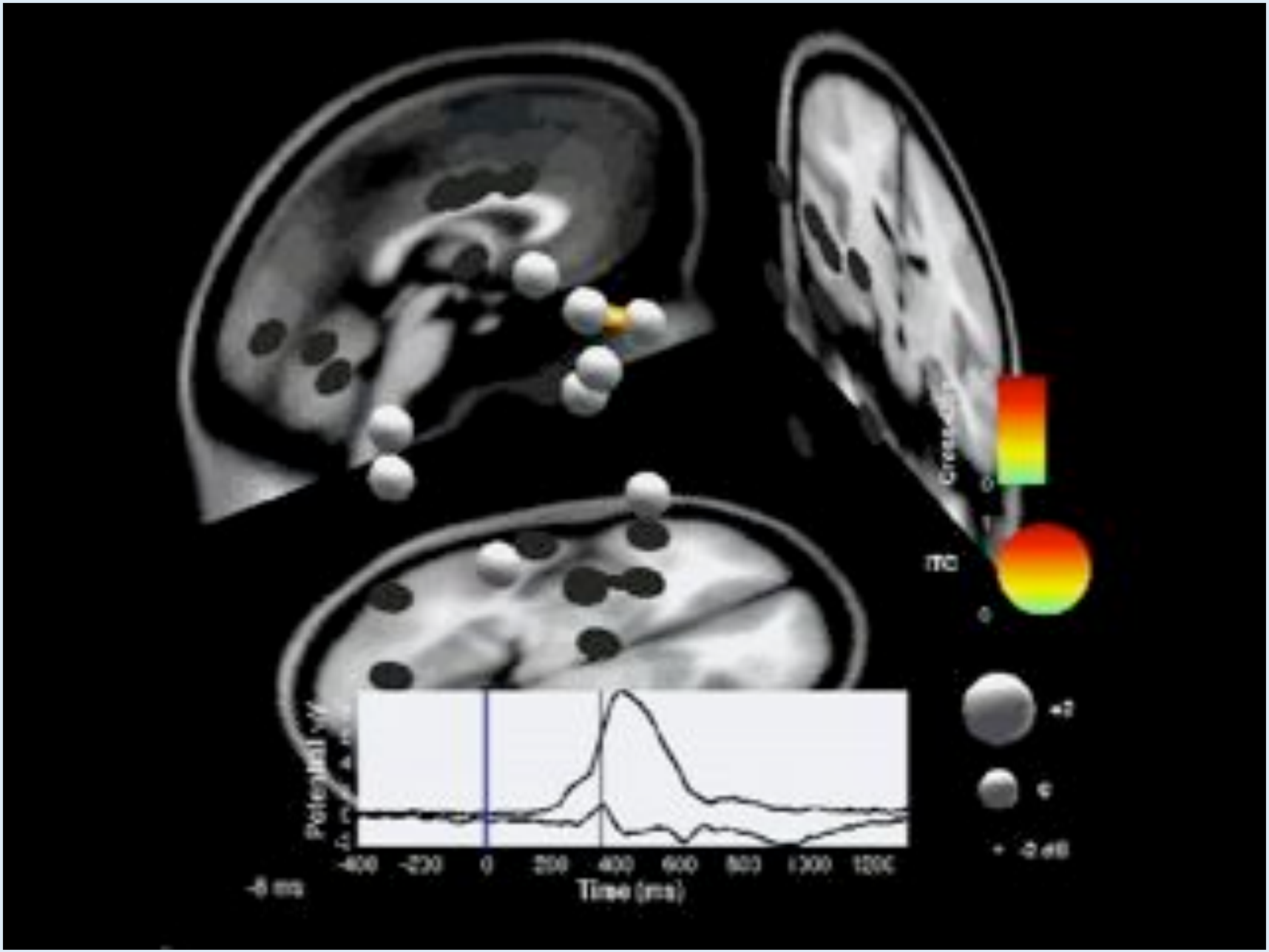


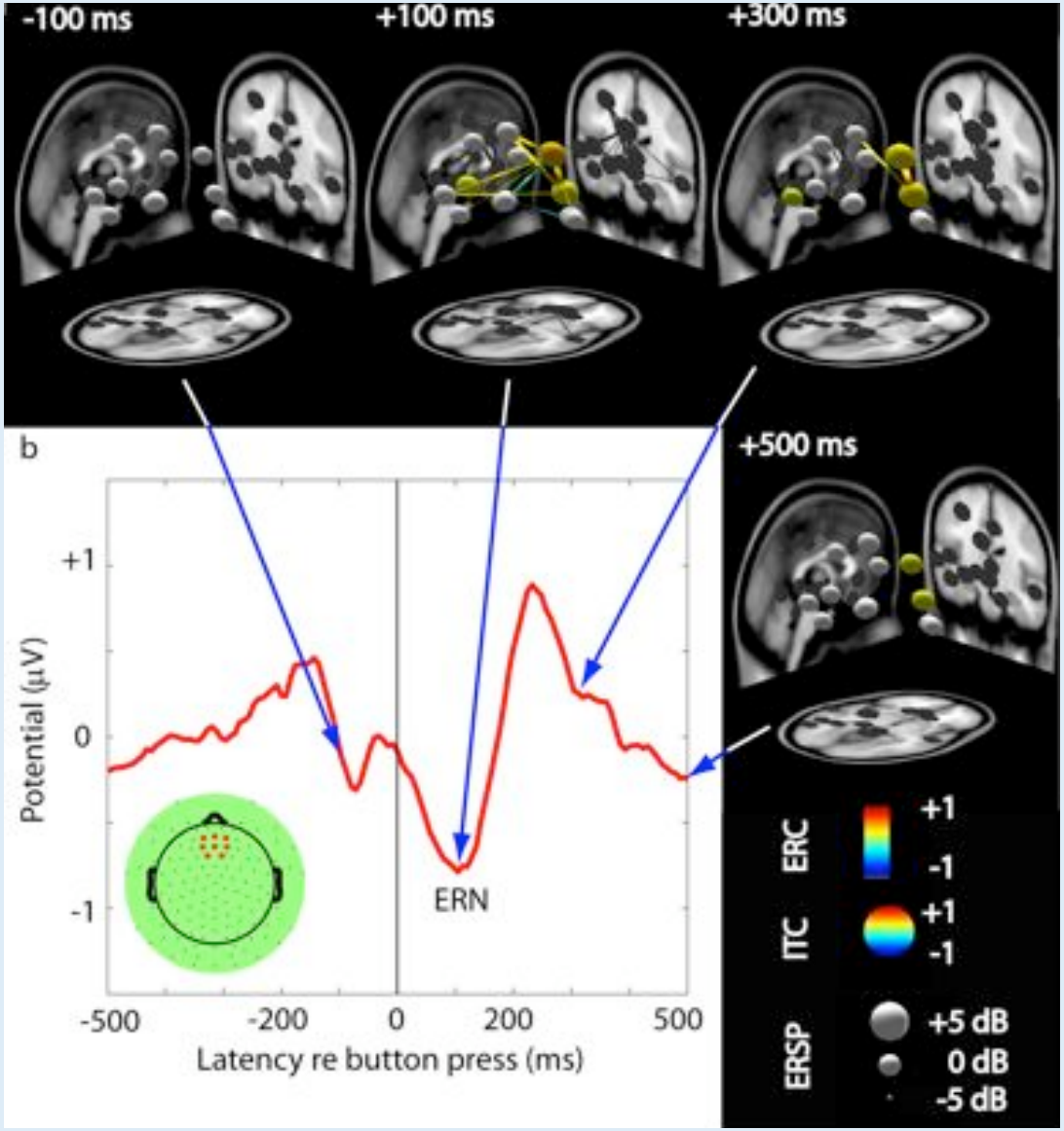
Figure 3.

Across-subject averages of alpha and gamma-band coherence between the fusiform gyrus and 15 other areas. A sharp transient face-selective increase in coherence centered at 200 ms is seen in all sites for alpha activity and a majority of sites in the gamma band. Abbreviations as in Figure 1.

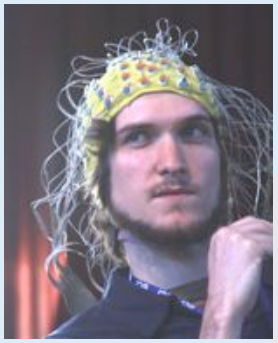
J Klopp, K Marinkovic, P Chauvel, V Nenov, E Halgren *Hum Br Map* 11:286-293 (2000)


ITC
-400
-200
0
200
400
600
800
1000
1200
Time (ms)

fEEG: Functional EEG Source Imaging

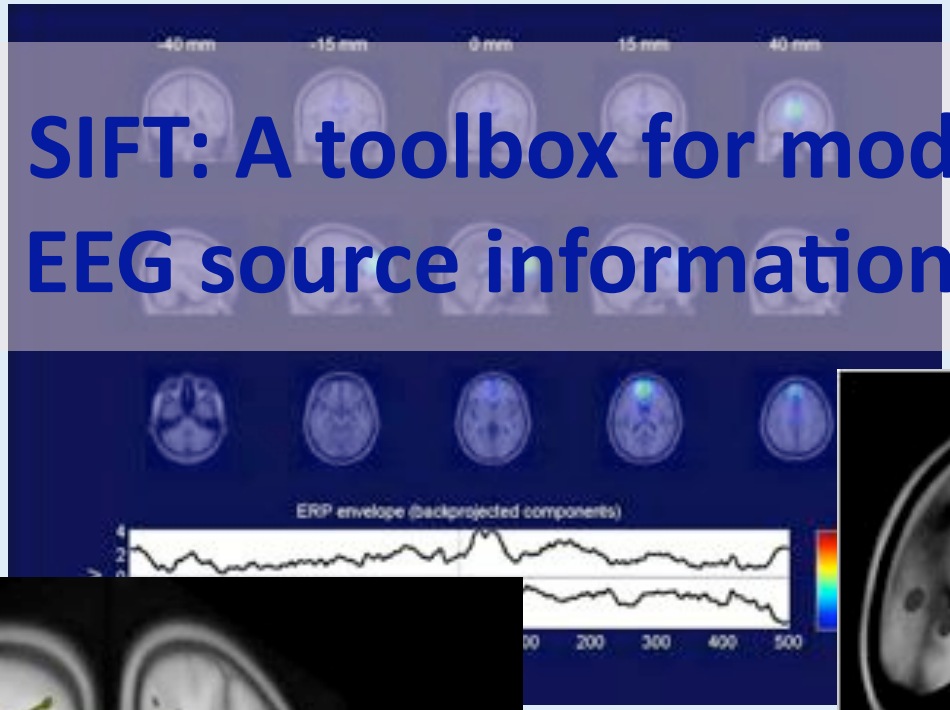


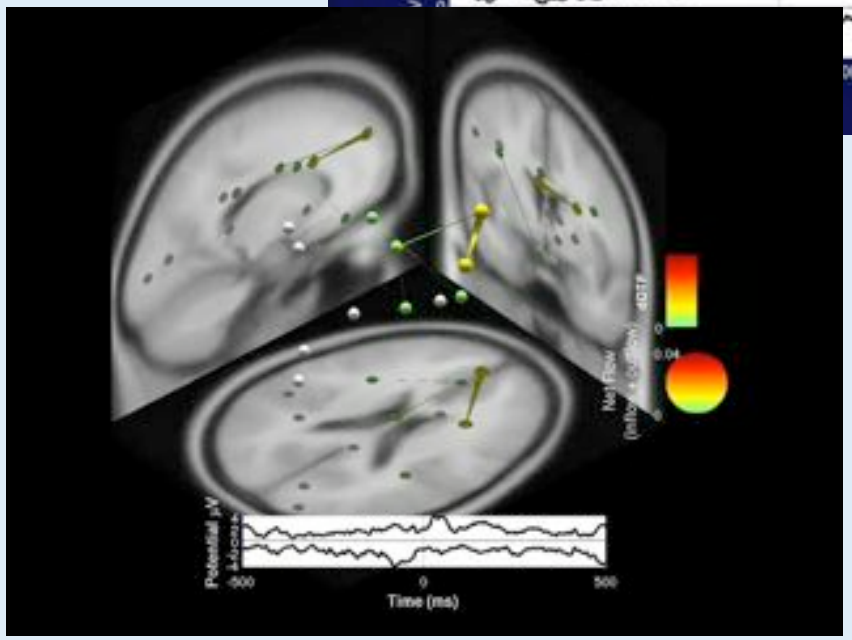
Rossen, Makeig, et al..

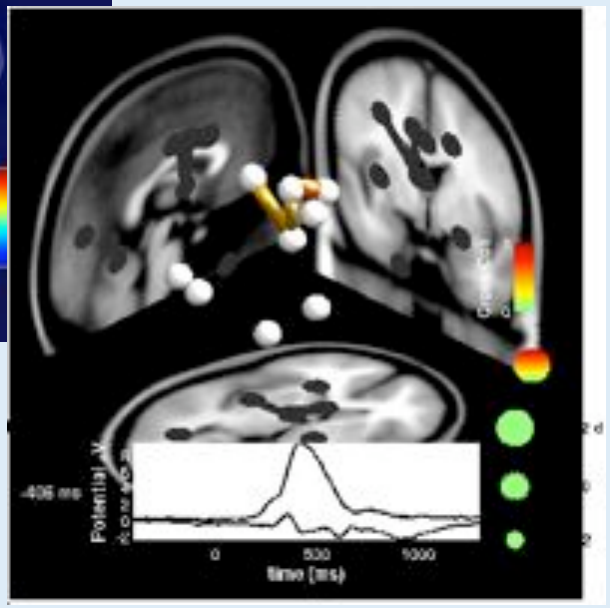


Transient EEG Network Connectivity

SIFT: A toolbox for modeling EEG source information flow







Tim Mullen, S. Makeig et al. unpublished

Uses for EEG?

What can EEG measure?

1 Alertness

2 Attention

3 Arousal

4 Anticipation

5 Affect

6 Awareness

7 Agency

8 Aha!

What can EEG measure?

1 Alertness

2 Attention

3 Arousal

4 Anticipation

5 Affect

6 Awareness

7 Agency

8 Aha!

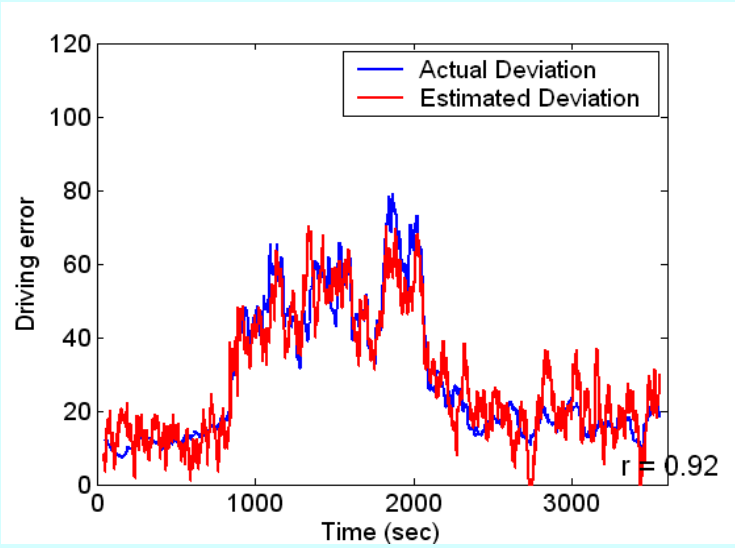
EEG-based Cognitive-State Monitoring

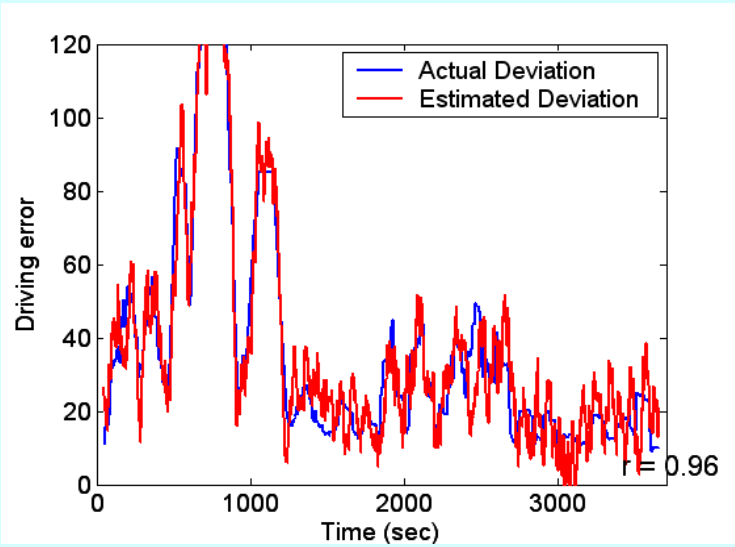
Estimating Cognitive states of the drivers

DSP and Display module

2.5 x 1.5 in

Sample Results

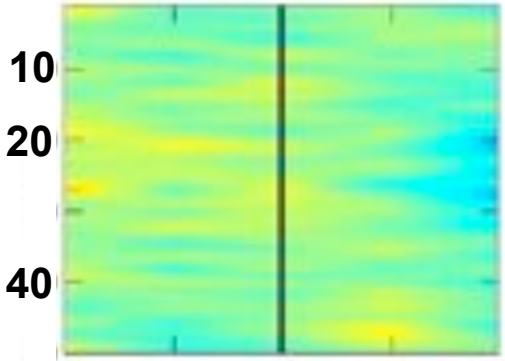




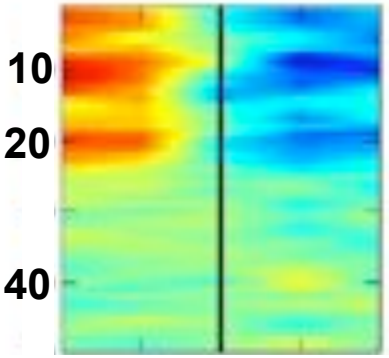
Lin at. al., *Proc. IEEE*, July 2008.

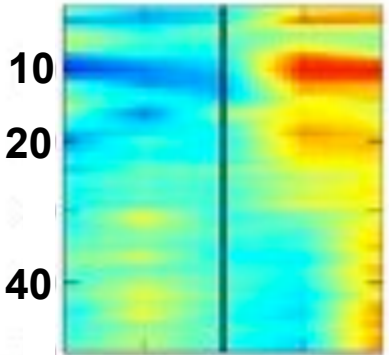
EEG and Attention

Frontocentral

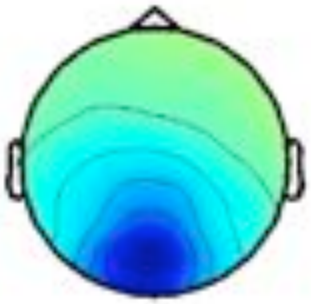


Left Alpha

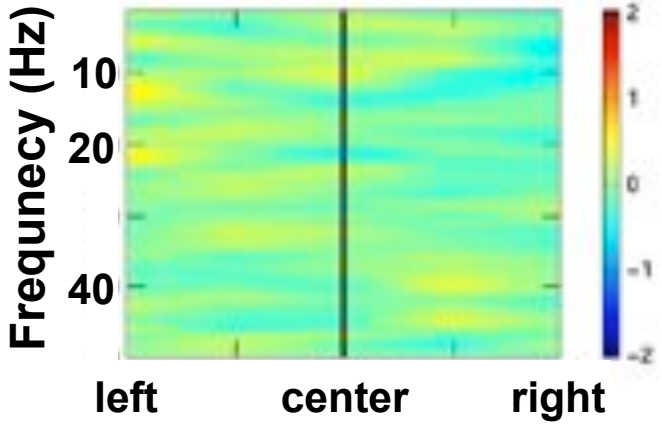




Right Alpha Component



Central Alpha

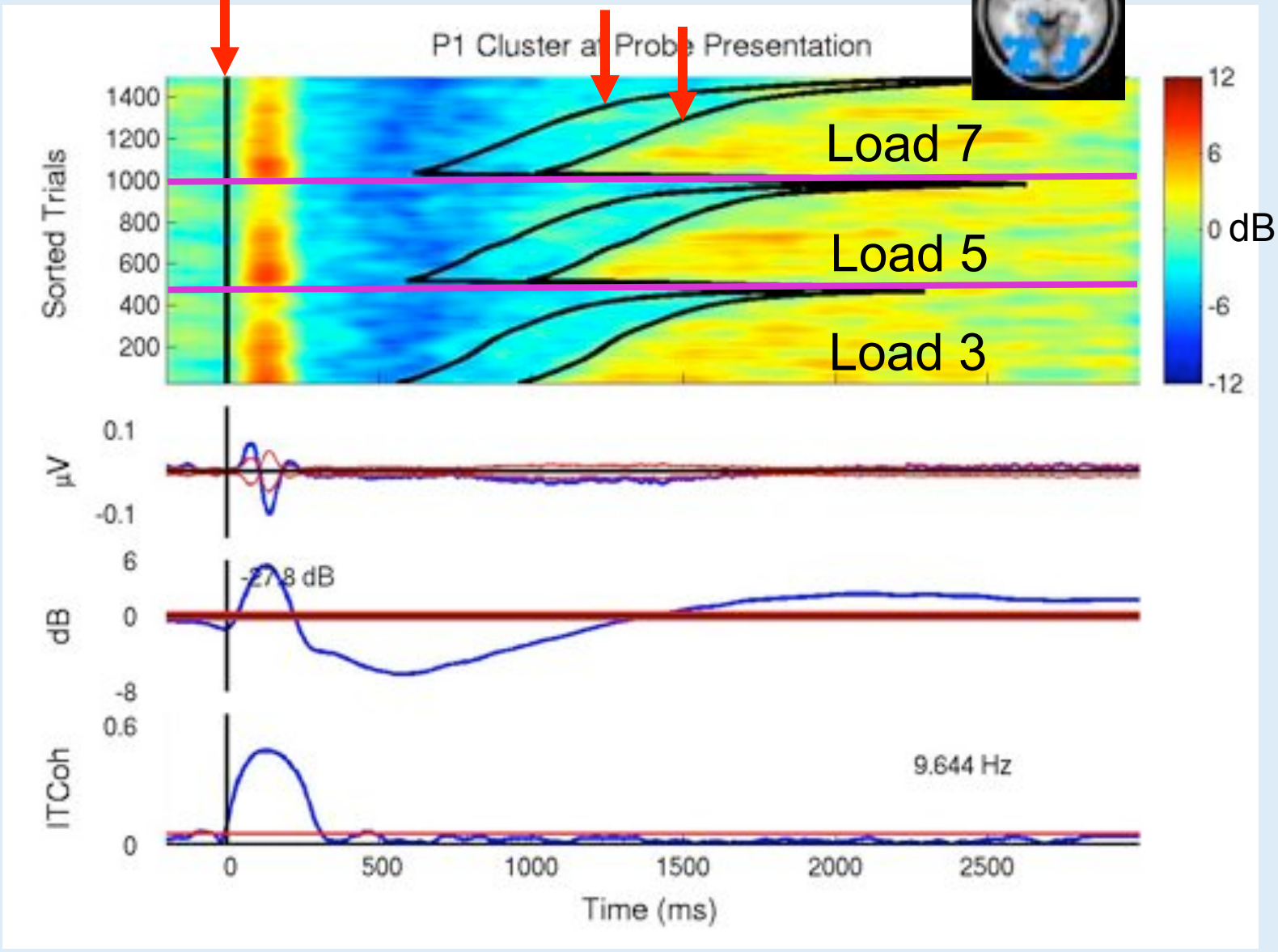


Baseline Spectrum

(1 s before stimulus)

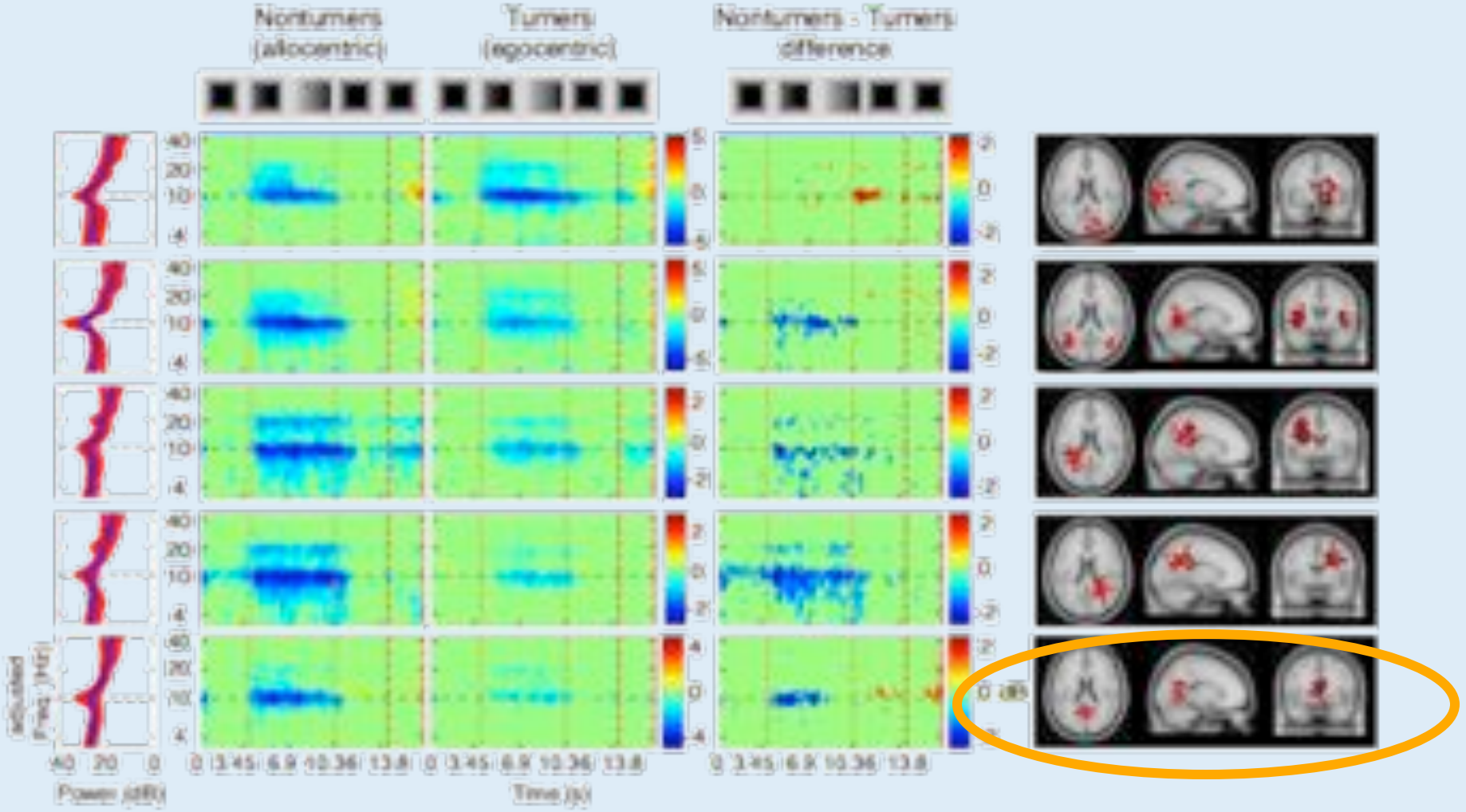
Westerfield & Makeig, 2001

EEG and Attention



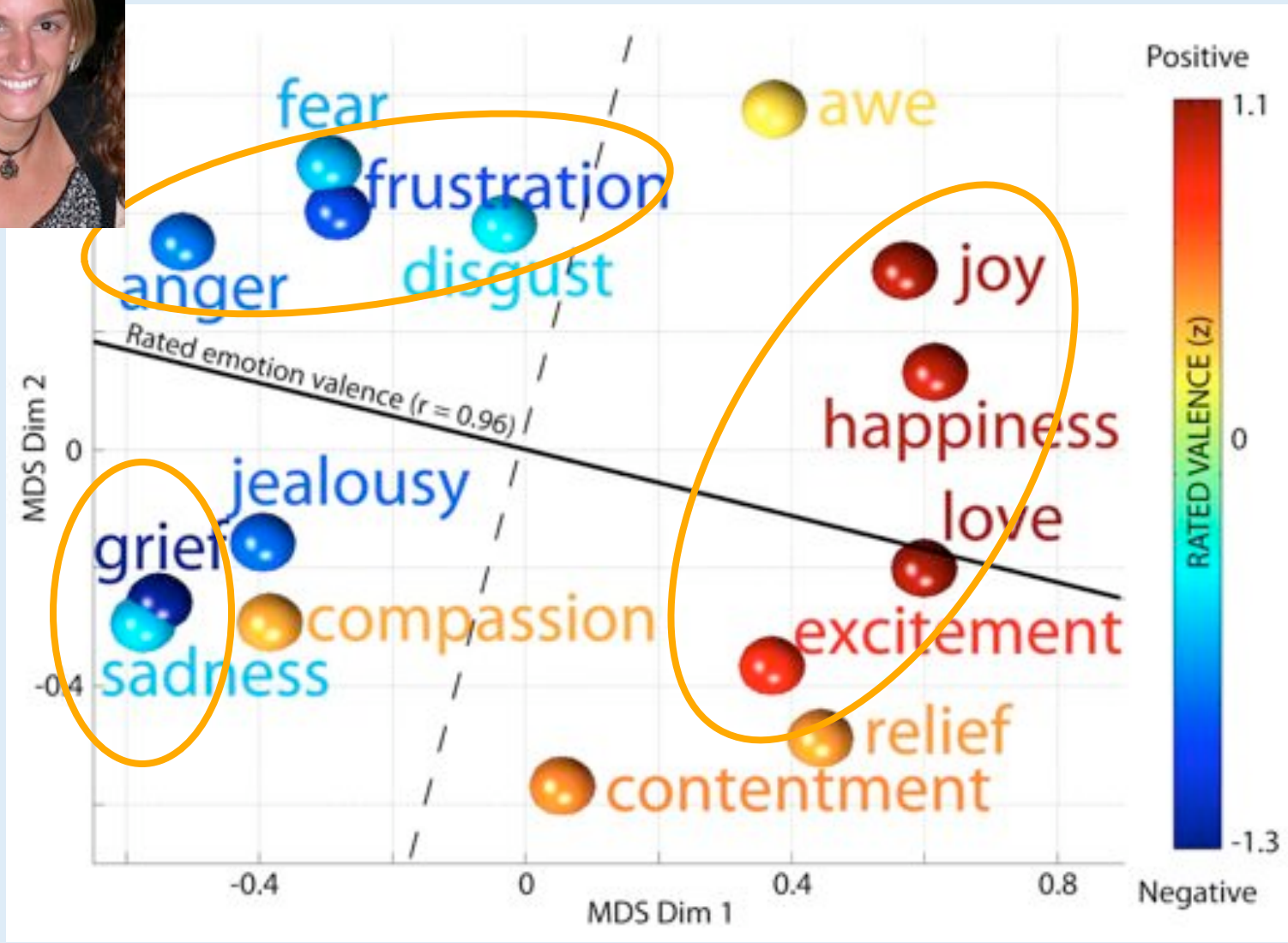
Onton & Makeig, 2006

Clusters distinguishing Turners & Nonturners



K. Gramann, J. Onton, & S. Makeig, 2008

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



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

BCILAB: A toolbox for building brain-computer interface models

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

Mobile Brain/Body Imaging Technology

- Current EEG, eye tracking, and motion capture systems **are portable**.
- In a few years, ***wearable*** microelectronic **MoBI systems** will be feasible.

Paradigm shift

ALERT !!

"EEG is something to use,

not just something to study…"

K. Gramann, T-P Jung & S . Makeig (2008)

New dimensions of EEG research and application

Although traditional EEG analysis methods have used relatively little of the abundant information about distributed brain dynamics contained in EEG data …

… new recording technology, and new analysis methods based in brain physiology allow mining much more of this information, and make possible the analysis of new experimental paradigms.

New feasible applications of EEG include:

- for EEG feedback for attention training
- for High-definition fEEG imaging for clinical research
- for X-high-definition electrocortical source imaging
- for Mobile brain/body imaging (MoBI)