William Blake

High-Resolution EEG Brain and Brain/Body Imaging

New Methods for Social Neuroscience Research

Scott Makeig

Institute for Neural Computation

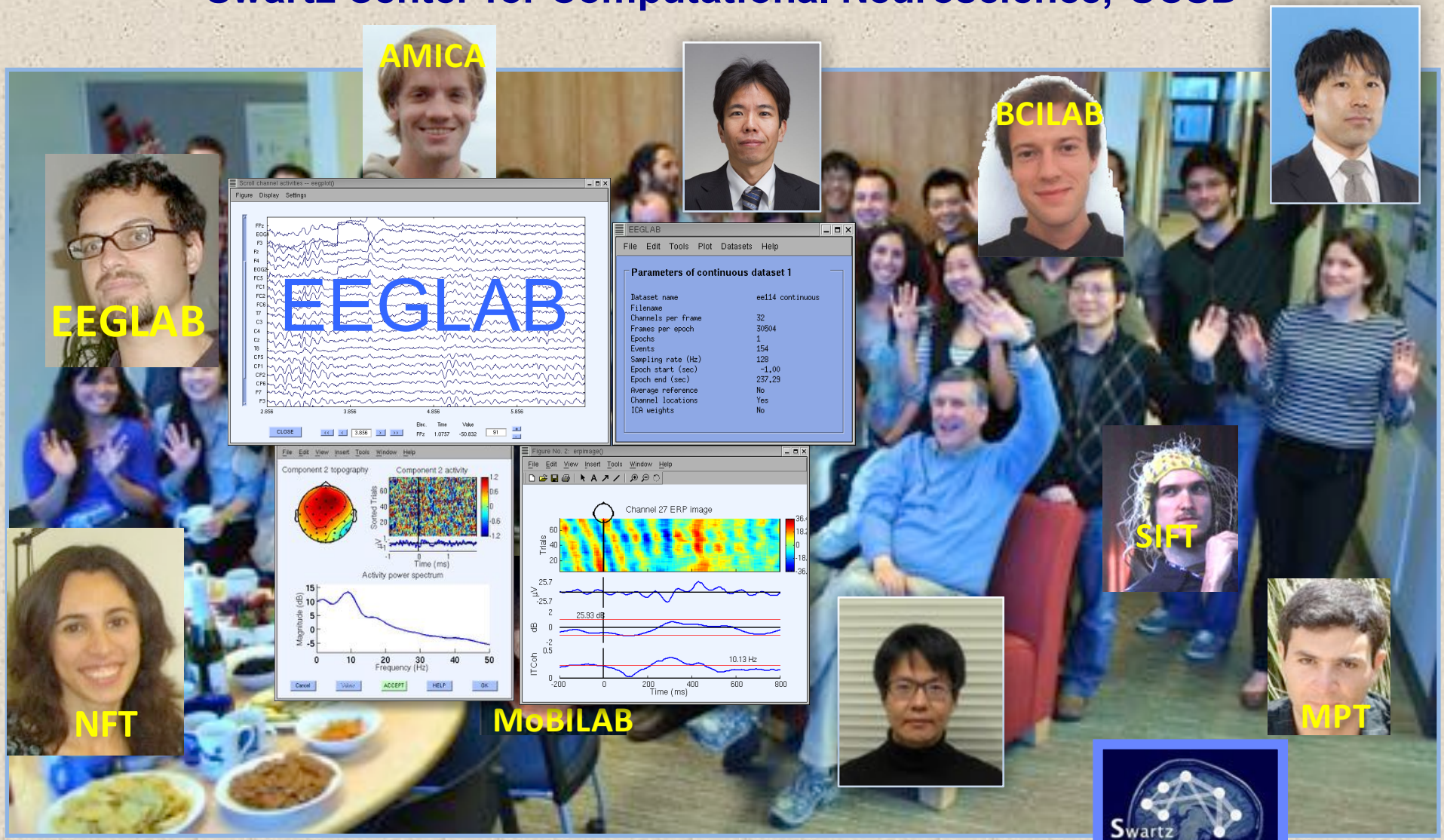
University of California San Diego

Electrical Neuroimaging Workshop on the Dynamic Social Brain

San Diego, CA

November, 2016

Swartz Center for Computational Neuroscience, UCSD



10th Anniversary SCCN Impromptu celebration 1/2/12

Embodied Agency

Brain processes

have evolved and function

to optimize the ***outcomes***

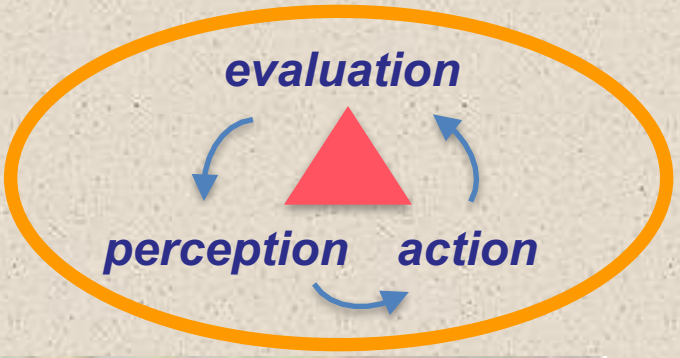
of the ***behavior***

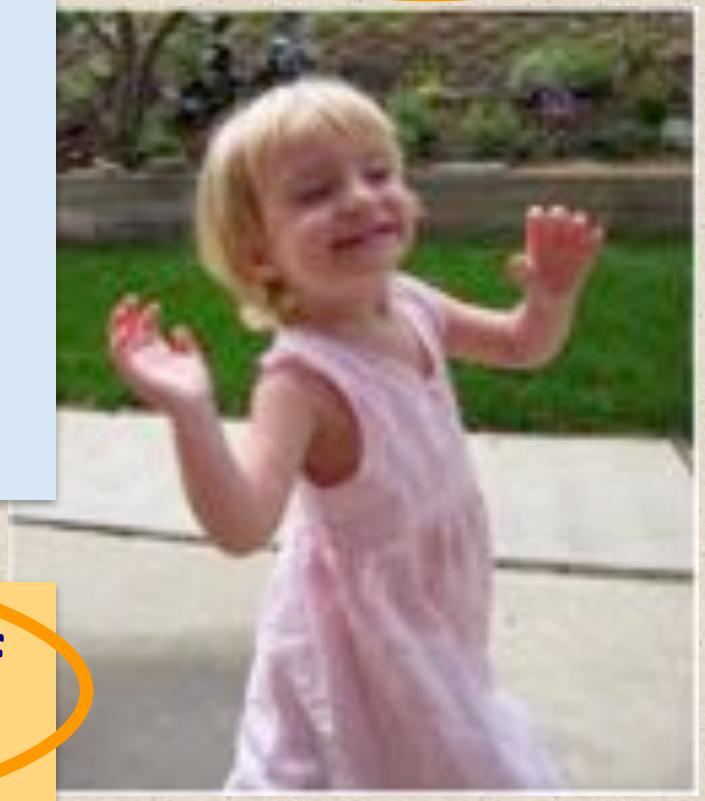
the brain organizes

in response to

perceived challenges

and opportunities.





Brains meet the challenge of the moment!

S. Makeig 2011

Embodied Cognition

Both our 'abstract' and our 'aesthetic' cognition are built on and are grounded in our embodied experience

→ as is *our social experience*

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

fEEEG / BMI / MoBI era …

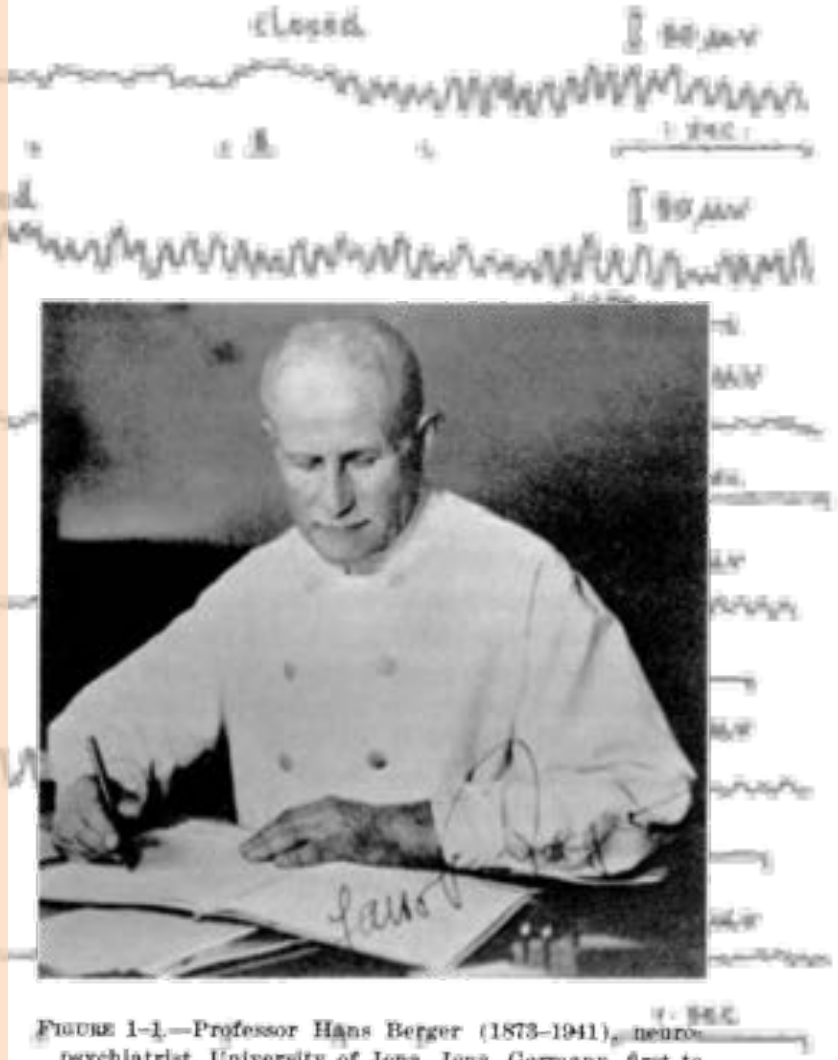
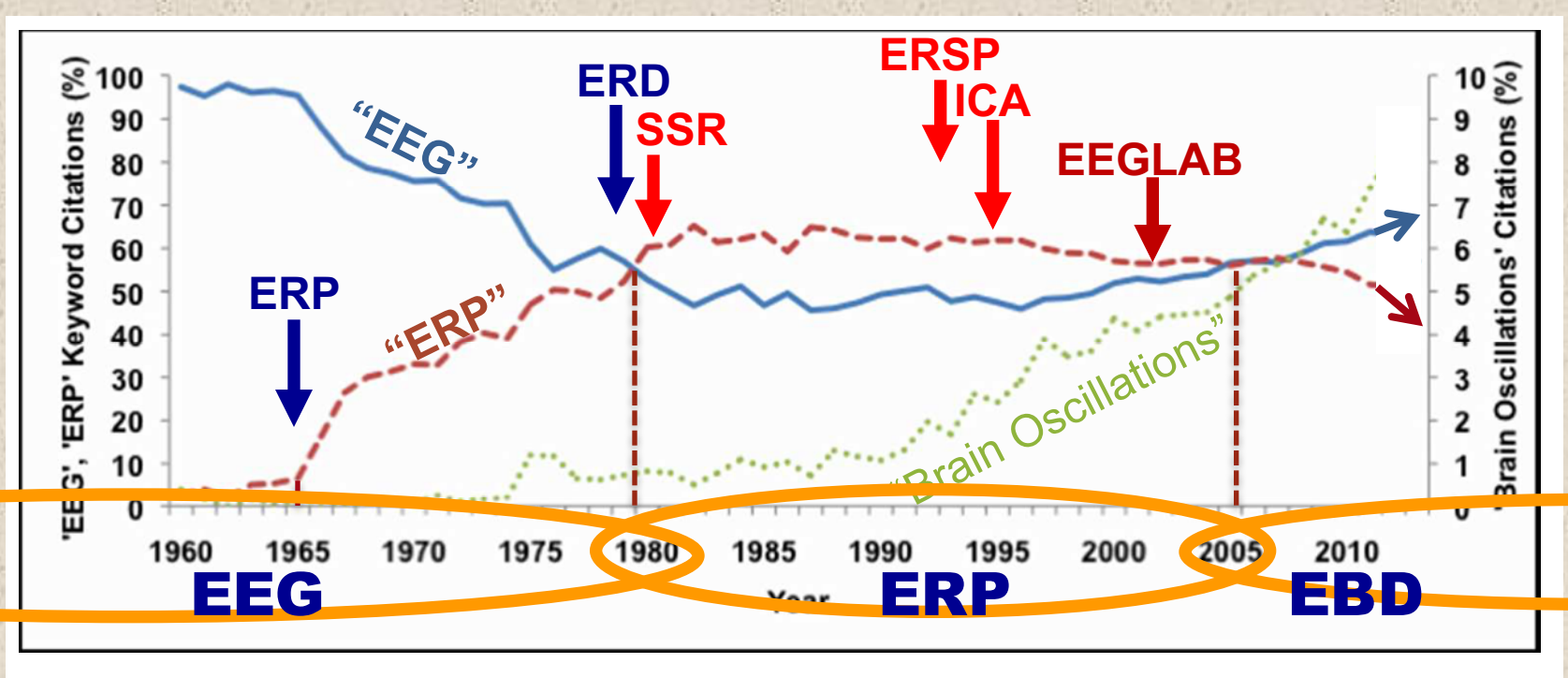


FIGURE 1–1.—Professor Hans Berger (1873–1941), neuropsychiatrist, University of Jena, Jena, Germany, first to discover and describe in 1929 a unique kind of electrical activity recorded from the brain of man, which he named the electroencephalogram (Elektrenkephalogramm).

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

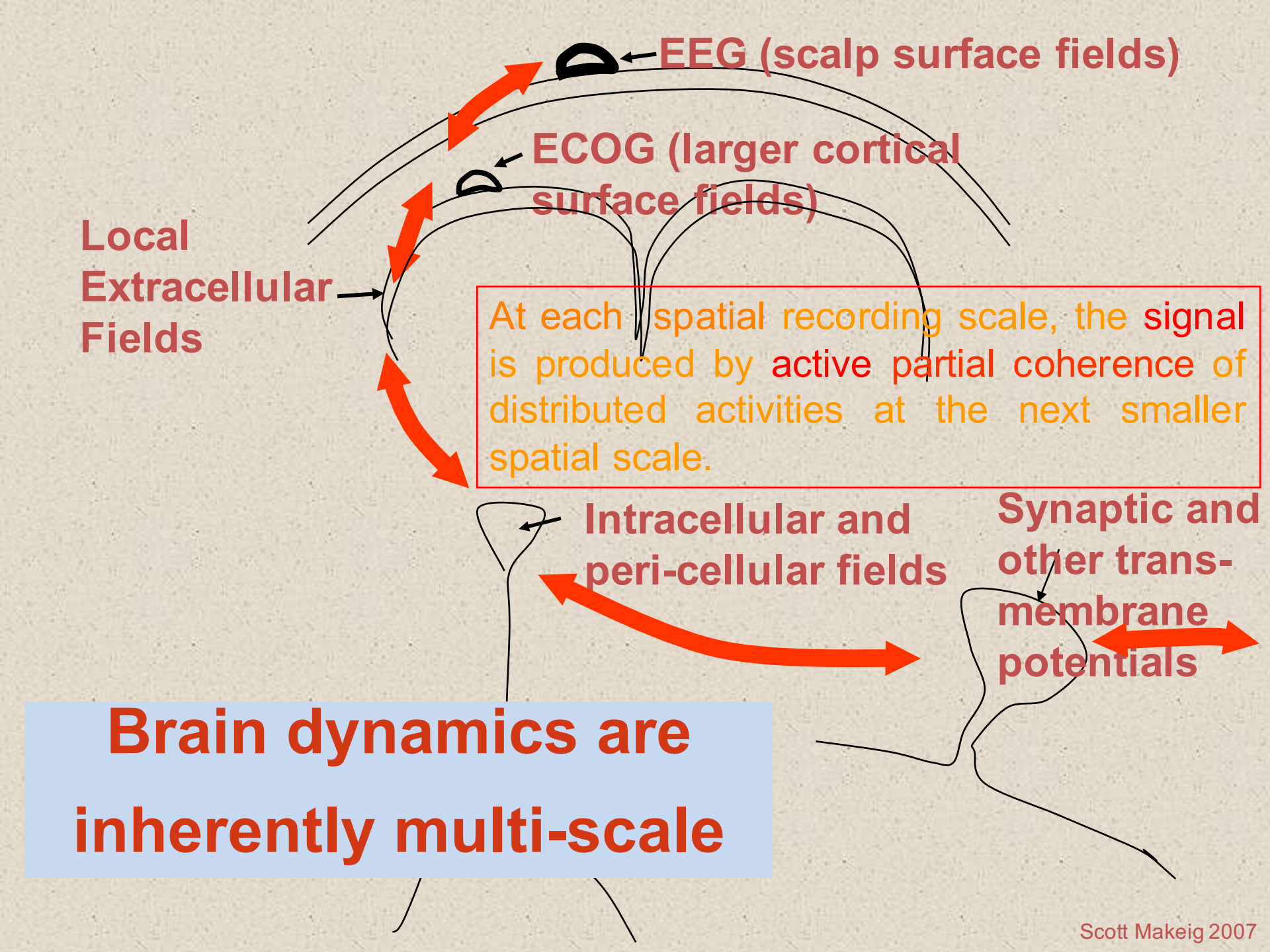
Three Modern Eras of EEG Research



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.

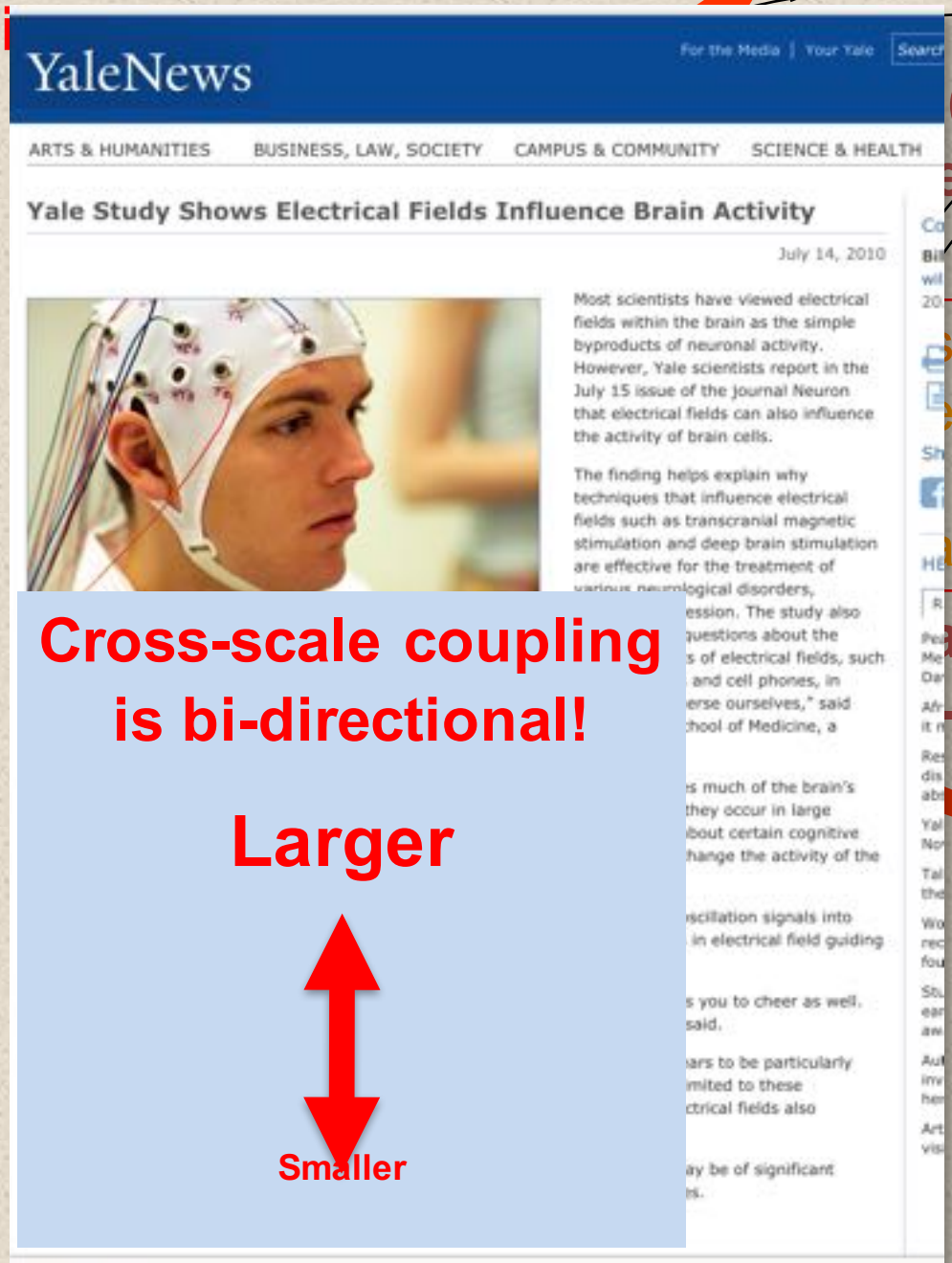
S. Makeig, 2016


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

Brain dynamics are

EEG (scalp surface fields)

(larger cortical
e fields)



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

acellular and
-cellular fields

Synaptic and
other trans-
membrane
potentials

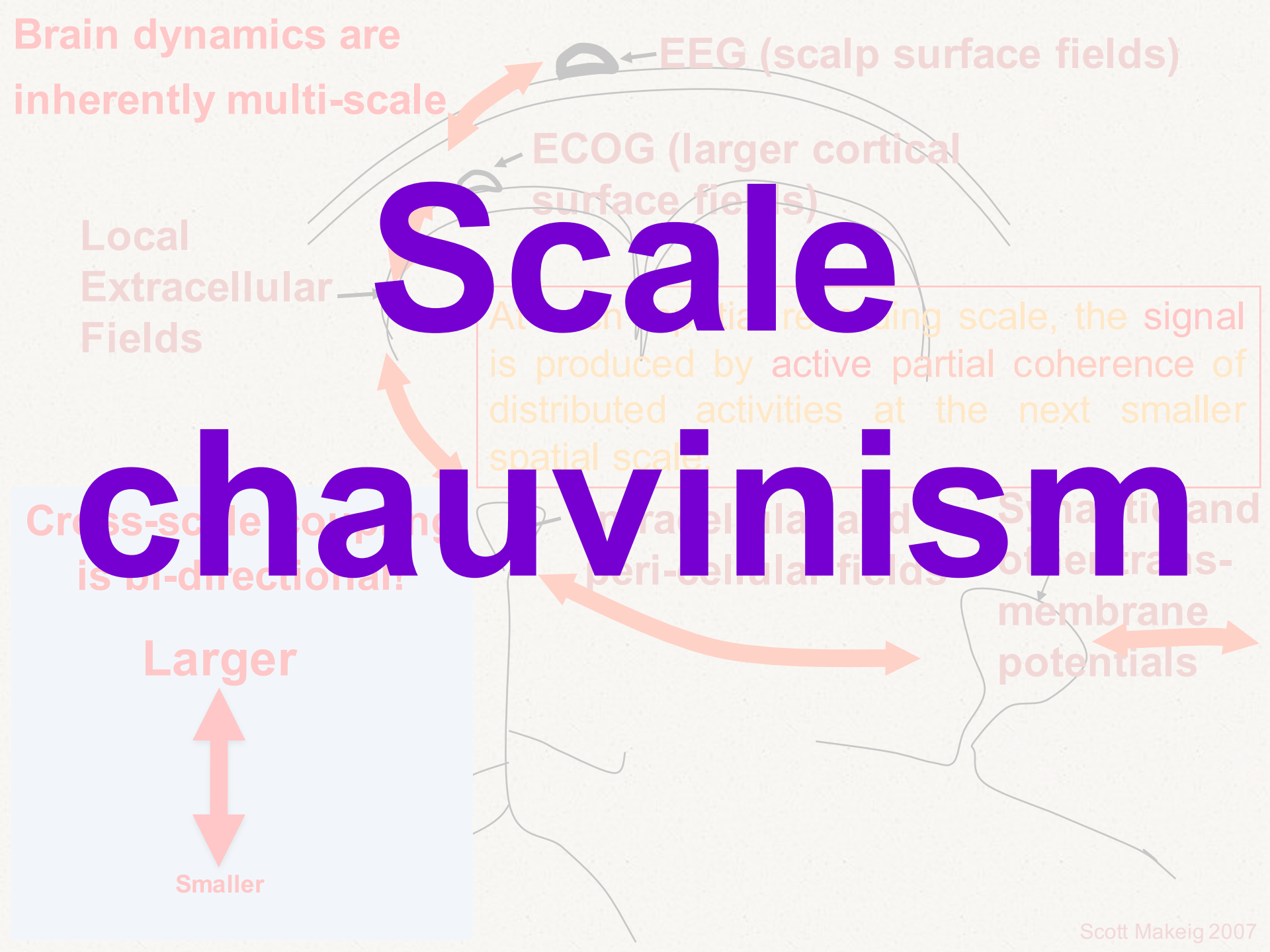
Cross-scale coupling is bi-directional!

Larger

Smaller

Any signal one records is not one unitary signal!

Electrical effects do not all proceed from small to big!



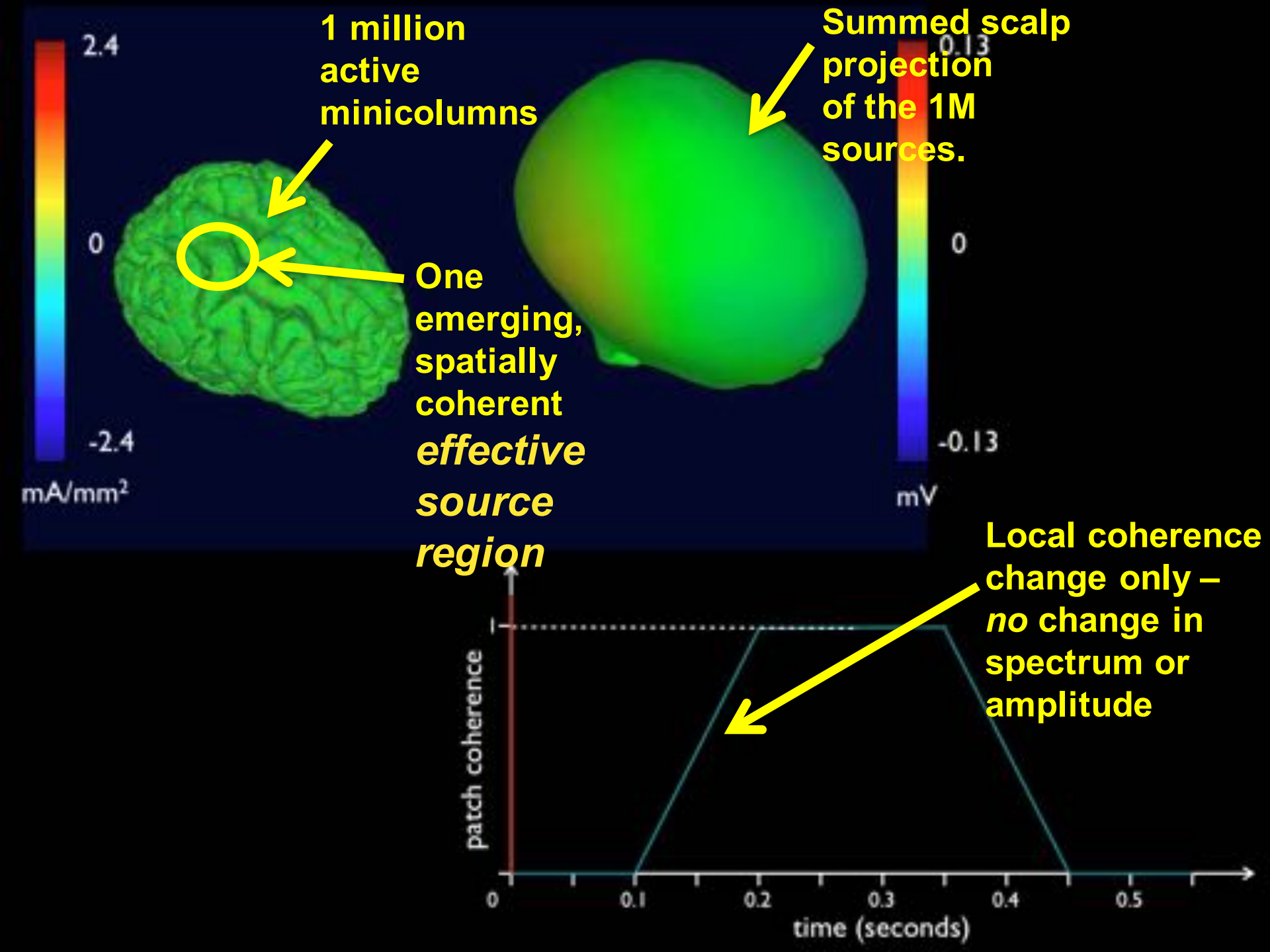
Scale chauvinism

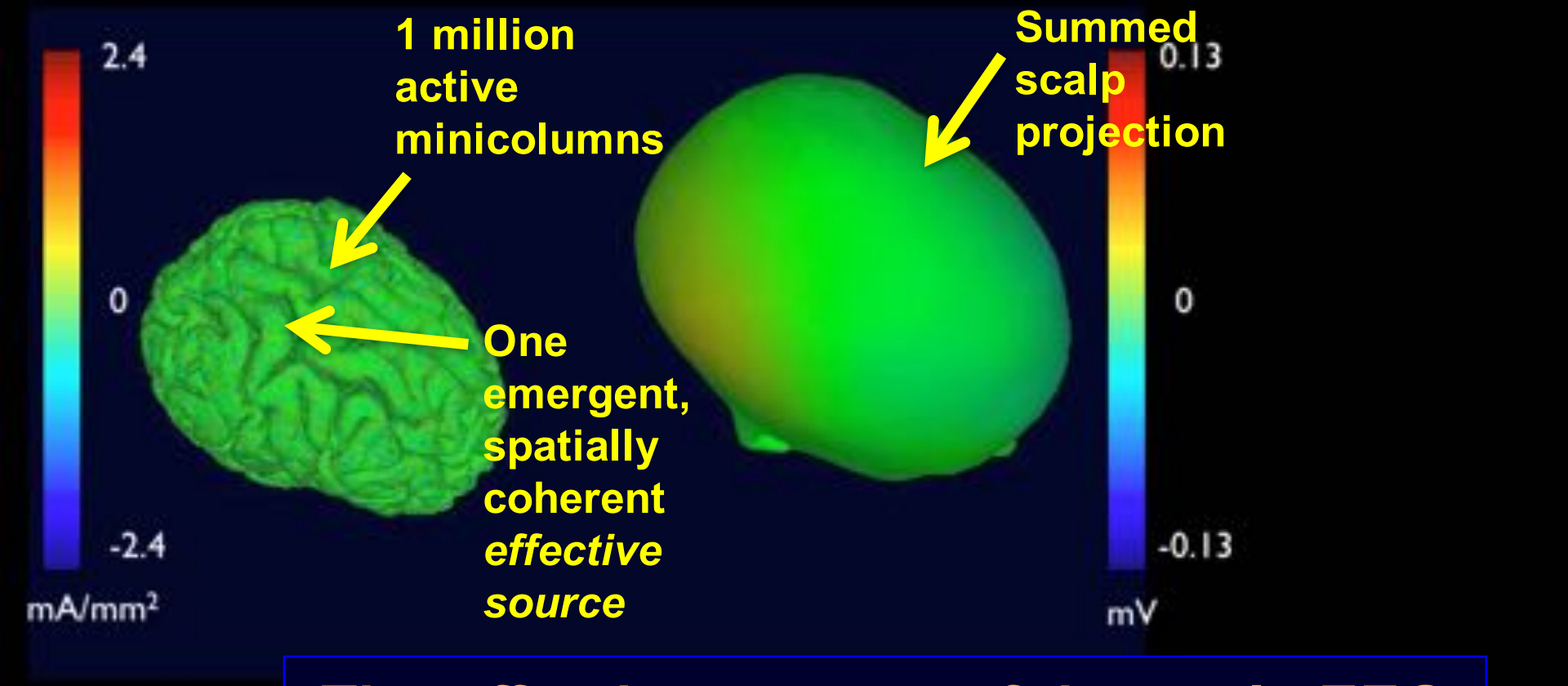
What is EEG?

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

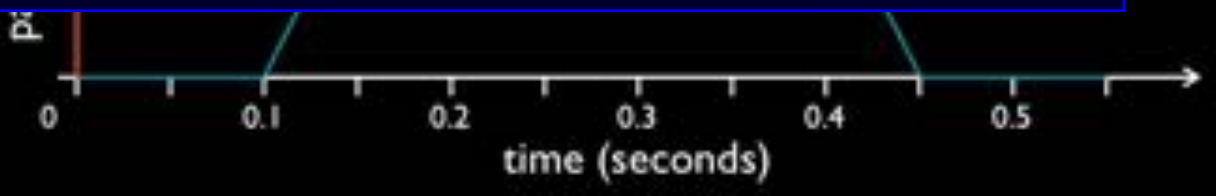
- **But *which* portion?**
- **Triggered and modulated *how*?**
- **With *what* functional significance?**

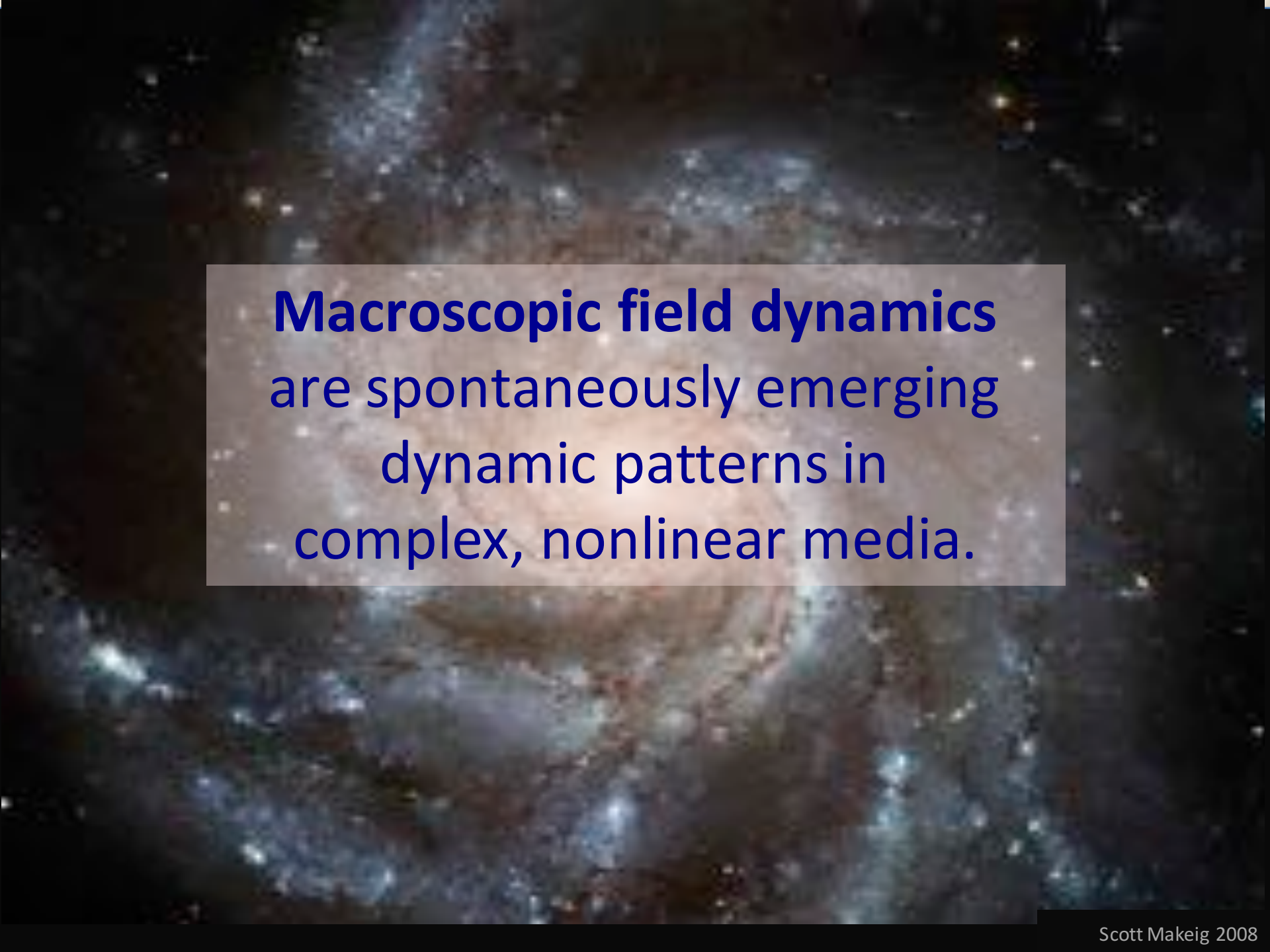
Cloud art: Berndnaut Smilde


1 million active minicolumns
Summed scalp projection of the 1M sources.
One emerging, spatially coherent *effective source region*
2.4
0
-2.4
mA/mm²
0.13
0
-0.13
mV
Local coherence change only – *no* change in spectrum or amplitude
patch coherence
0
0.1
0.2
0.3
0.4
0.5
time (seconds)



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




Macroscopic field dynamics
are spontaneously emerging
dynamic patterns in
complex, nonlinear media.

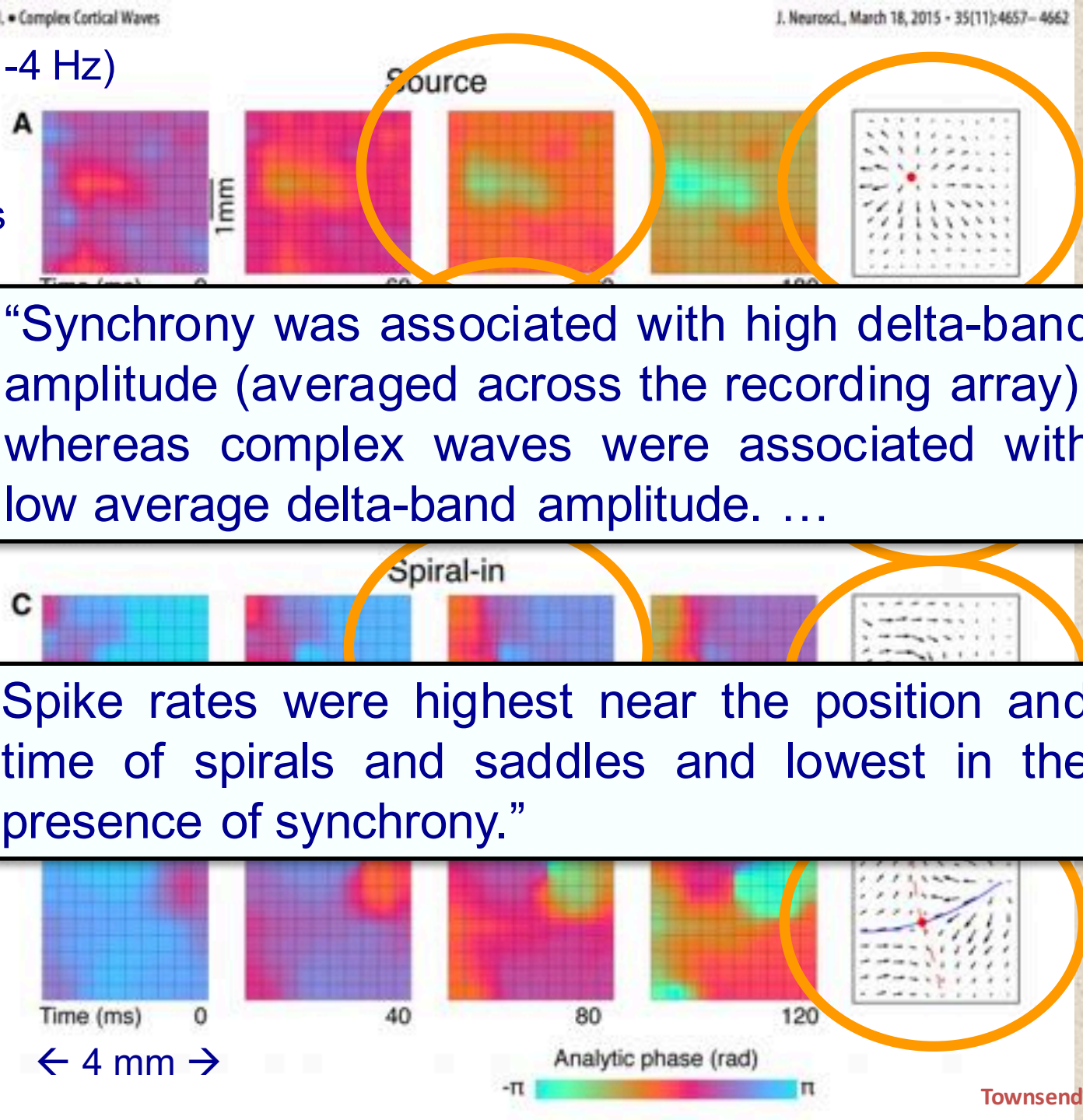
The spatiotemporal field dynamics of cortex have not yet been imaged on multiple spatial scales simultaneously !

Alan Friedman

Phase cones (Freeman)

Avalanches (Plenz)

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. …

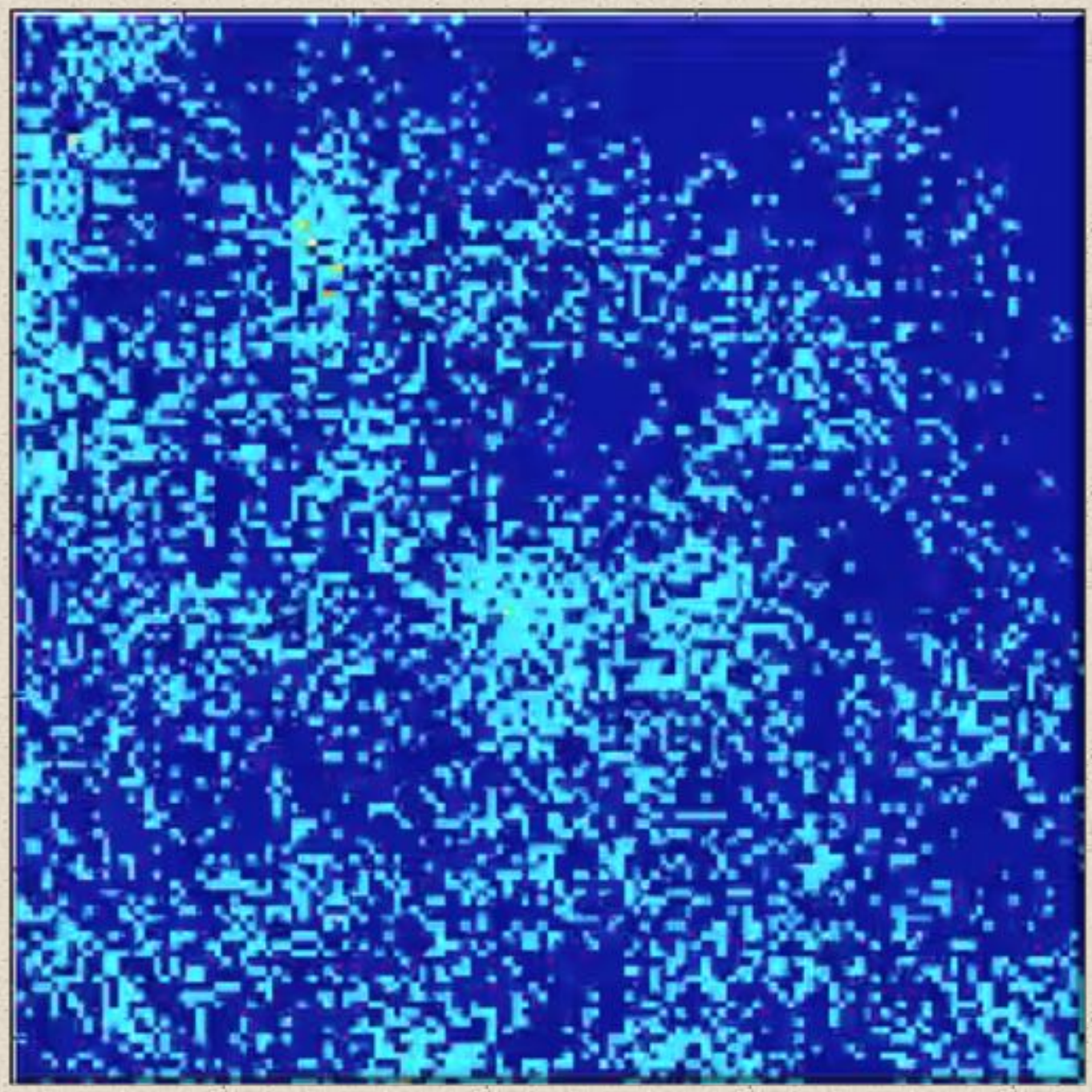
Spike rates were highest near the position and time of spirals and saddles and lowest in the presence of synchrony."

Simple patterns

Complex patterns

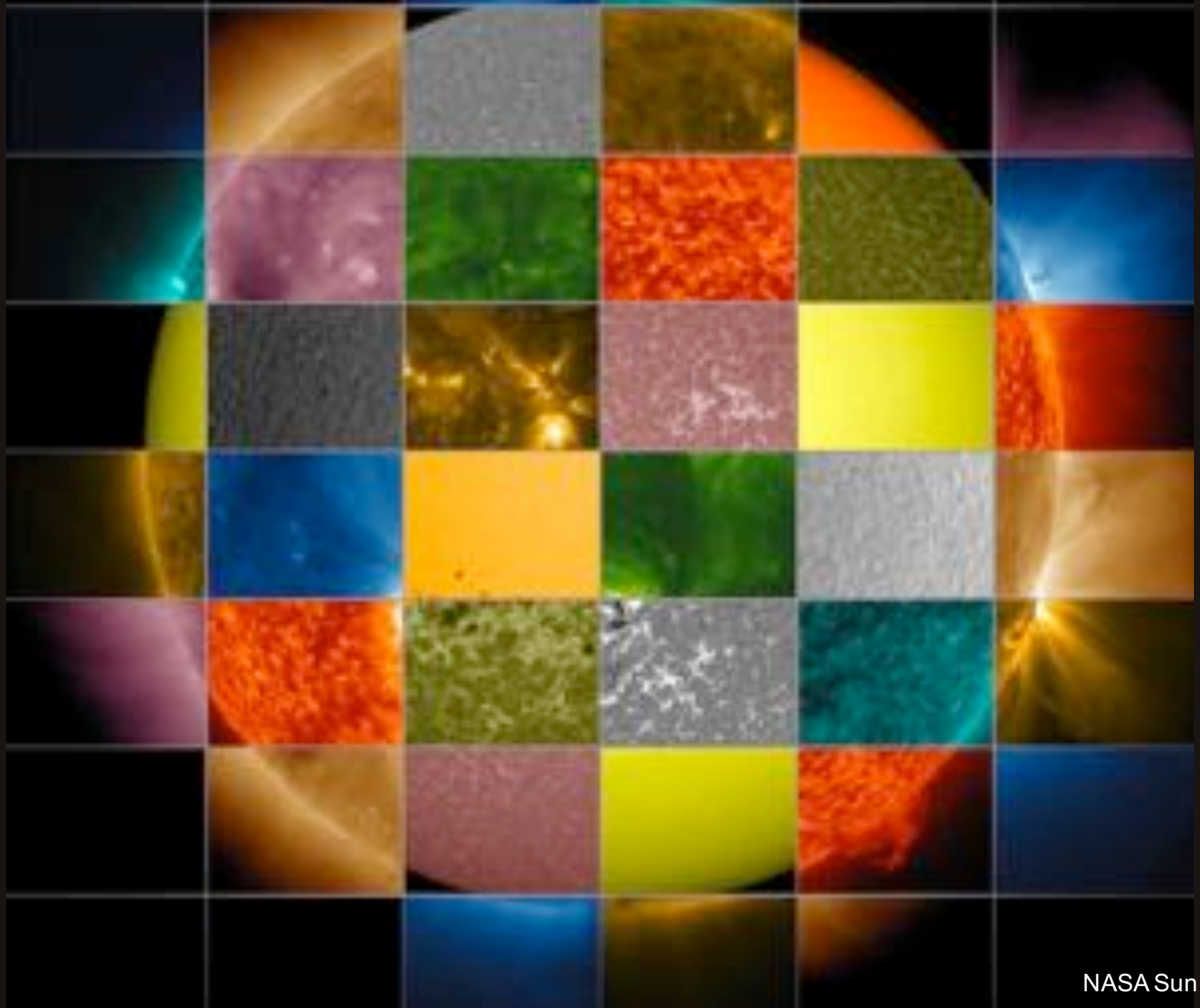
Townsend et al., 2015

Simulation



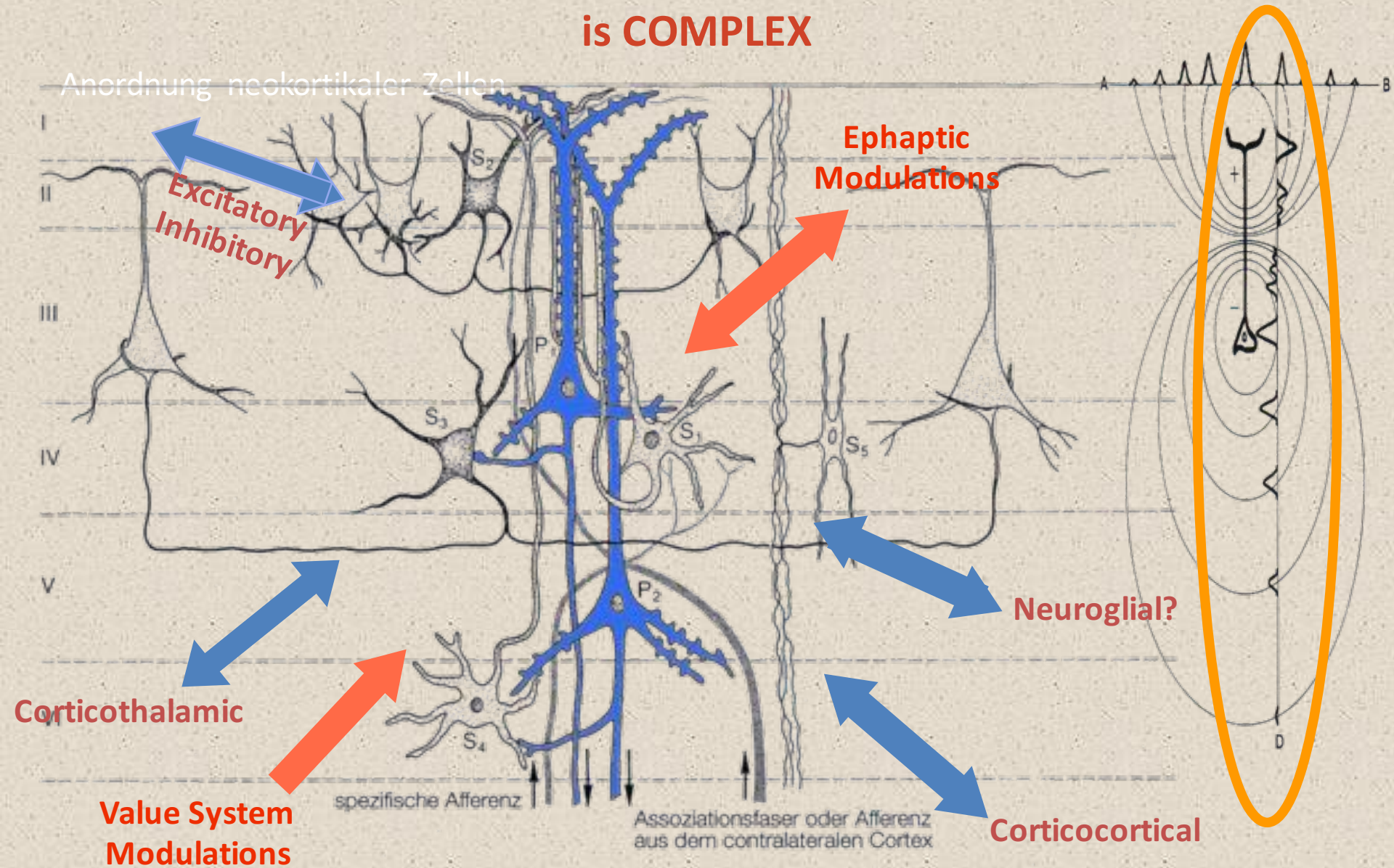
Stan Anderson

Spatial patterning may depend on frequency



NASA Sun Observatory

The generation and modulation of EEG / LFP is COMPLEX



S. Makeig 2007

Scalp EEG

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

S. Makeig 2007

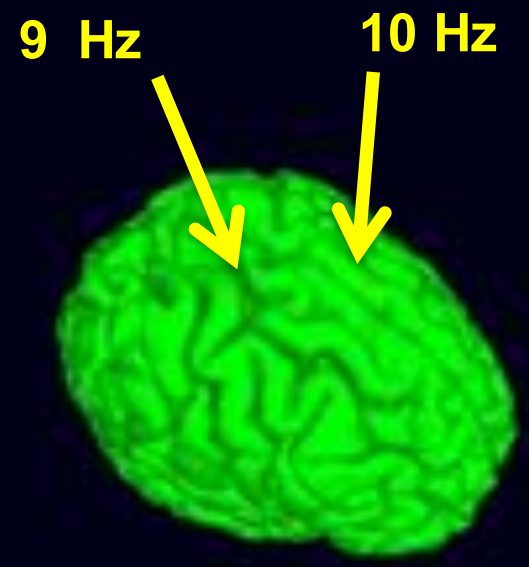
The very broad EEG point-spread function

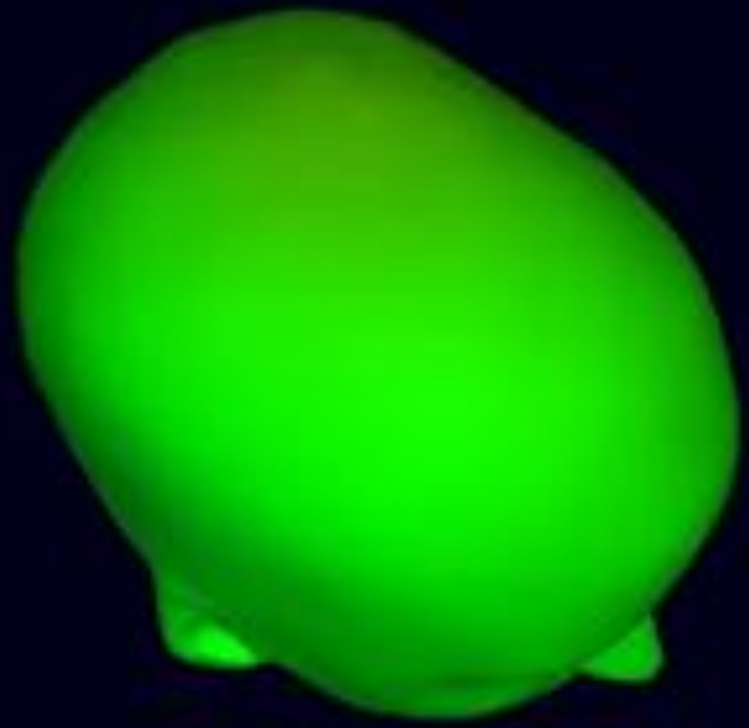
Single simulated parietal source →

Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The very broad EEG point-spread function





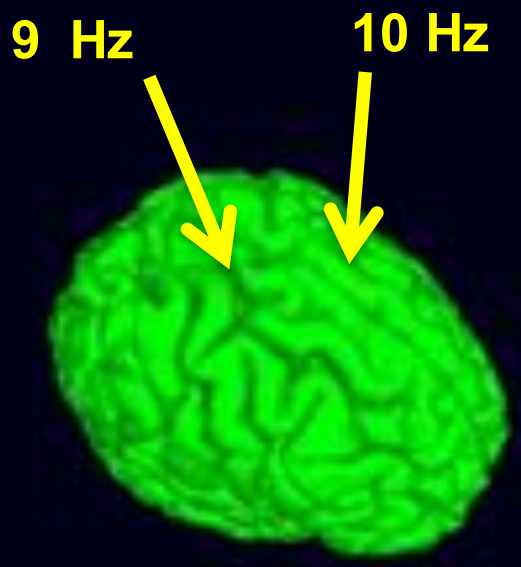
Two spatially static cortical sources

Scalp projection

Z. Akalin Acar & S. Makeig (2012)

The very broad EEG point-spread function

Phenomena



Two spatially stationary cortical effective sources

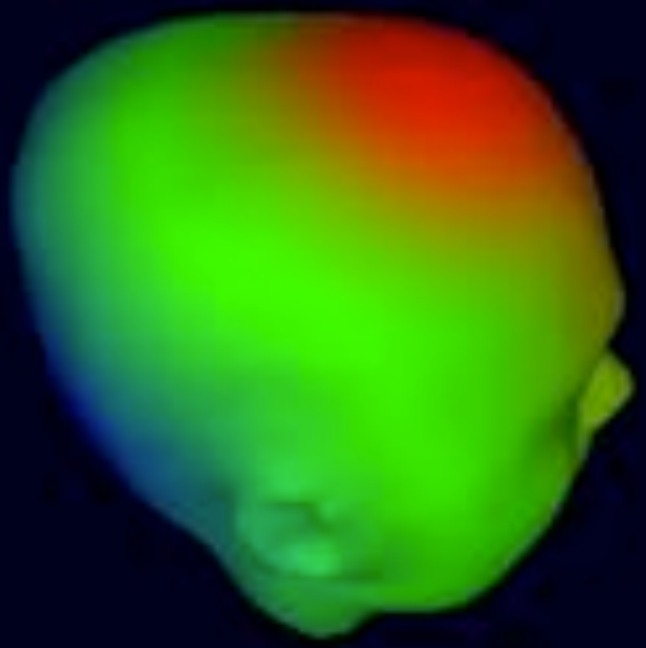
Epiphenomenal

ep·i·phe·nom·e·non -- a secondary effect or byproduct that arises from but does not causally influence a process.

Summed scalp projection

Z. Akalin Acar & S. Makeig (2012)

Summed scalp projections of 13 effective brain sources



Epiphenomenal Impressions

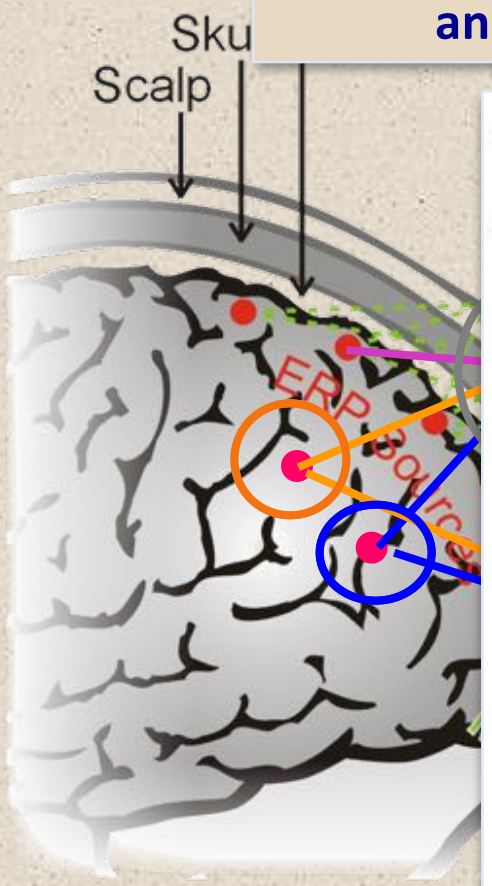
Causal Phenomena

Z. Akalin Acar & S. Makeig 2016

Blind EEG Source Separation by Independent Component Analysis

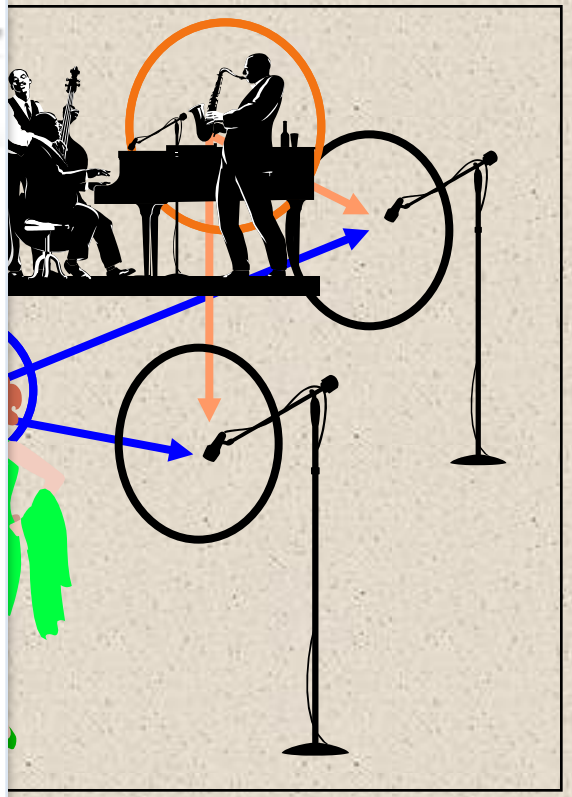
Tony Bell, developer of Infomax ICA

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



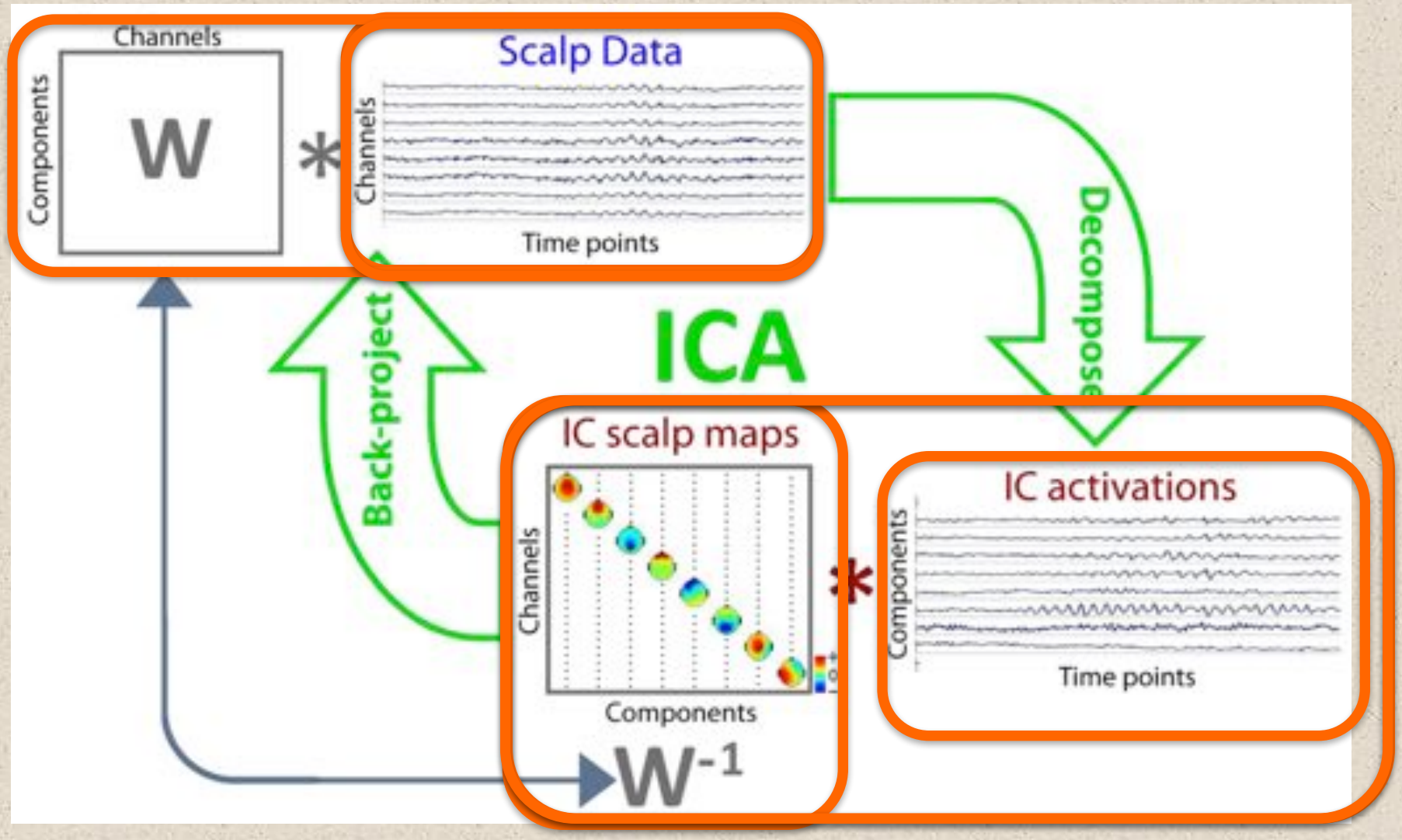
Independent Component Analysis of Electroencephalographic Data

Abstract



S. Makeig, S. Enghoff (2000)

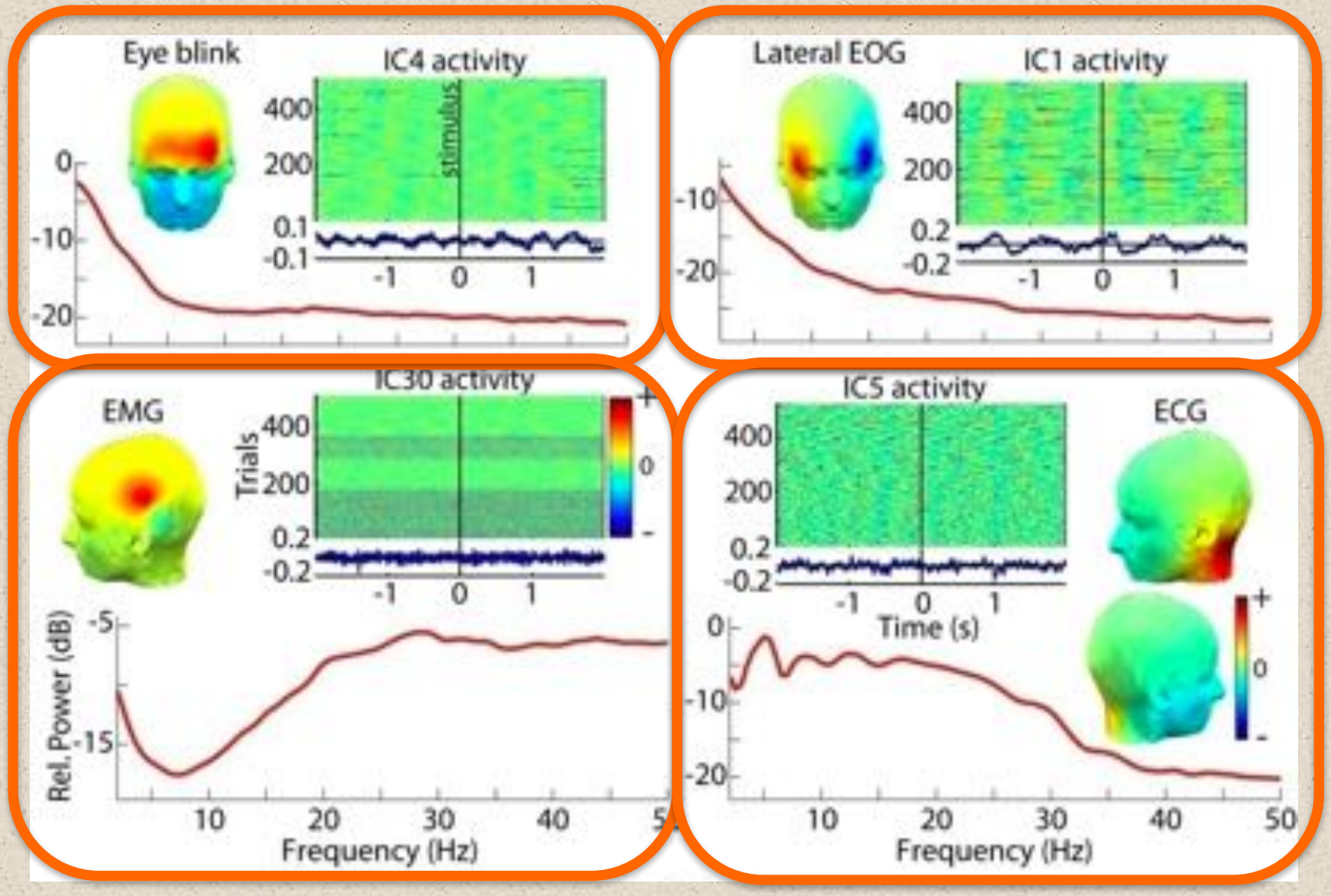
ICA is a linear data decomposition method



Mixing_Matrix * IC_Activations = Scalp_Data

Makeig & Onton, 2011

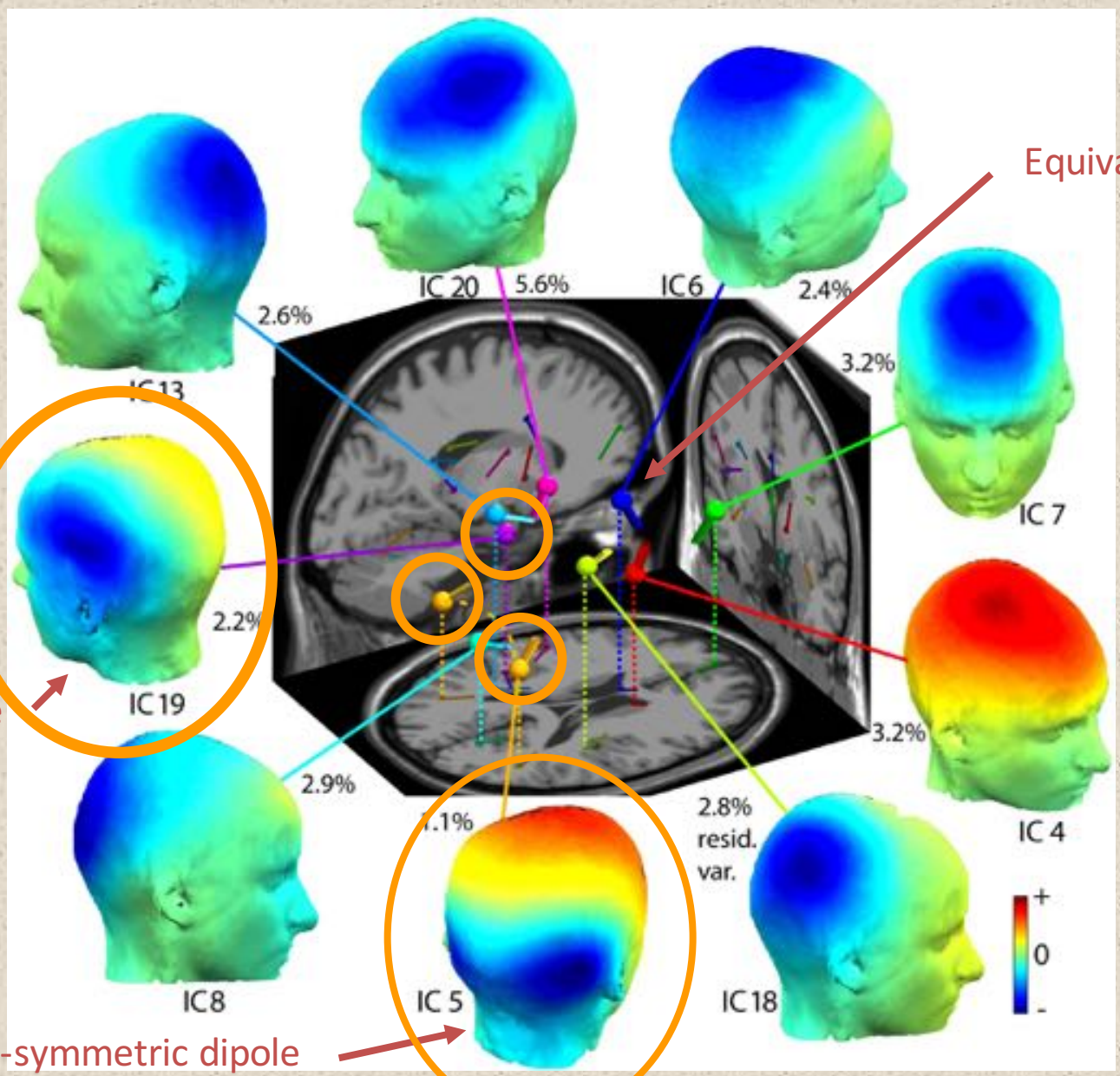
ICA finds Non-Brain Independent Component (IC) Processes …



… separates them from the remainder of the data …

J. Onton & S. Makeig 2006

ICA also separates cortical brain IC processes

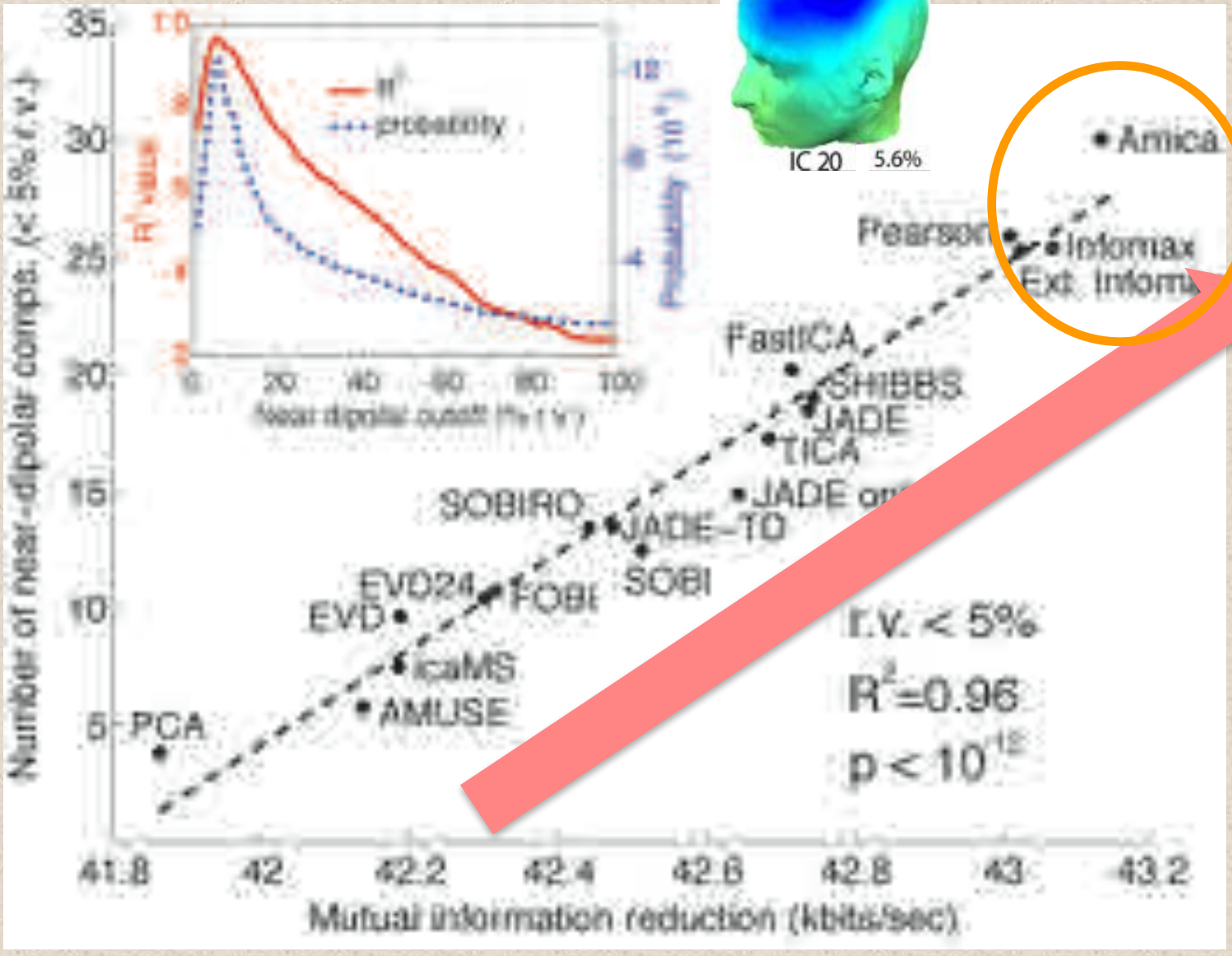


Equivalent dipoles

Single dipole component

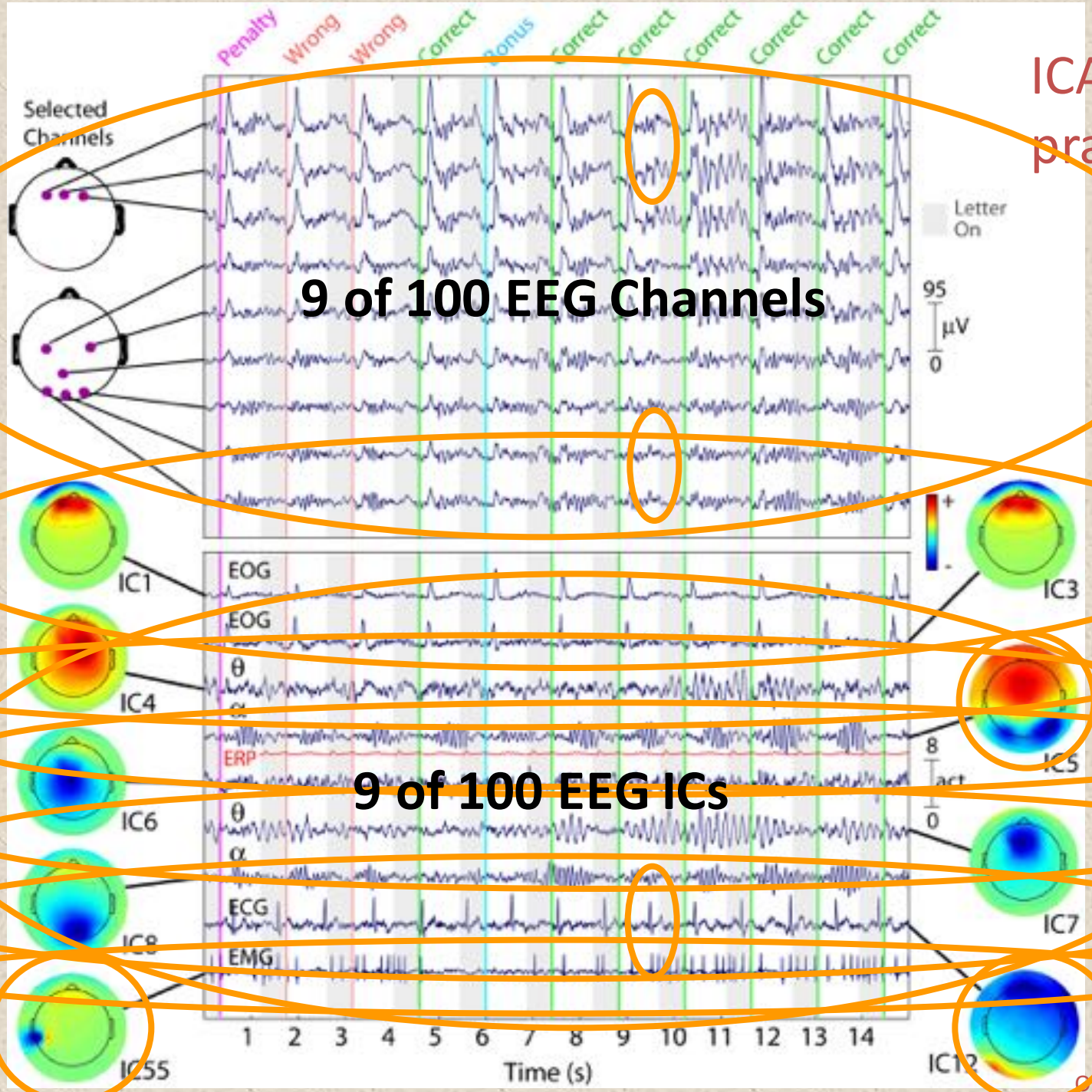
Dual-symmetric dipole component

Julie Onton & S. Makeig (2006)



A. Delorme, J. Palmer, S. Makeig, 2009

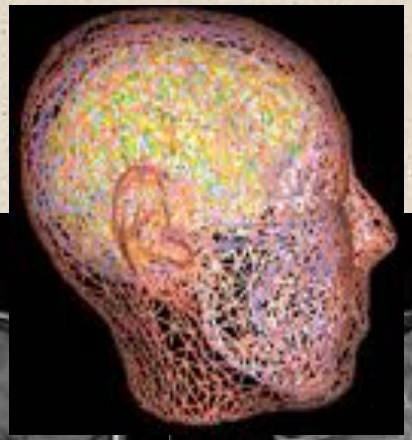
ICA in practice



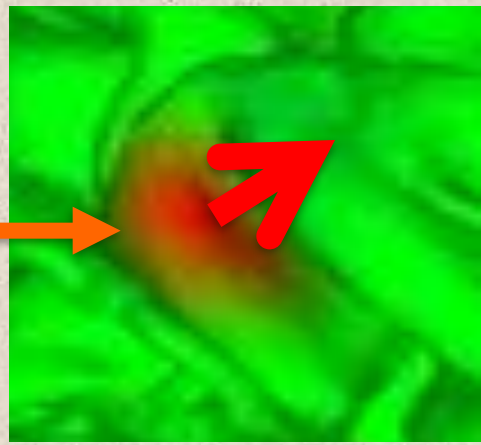
Onton & Makeig, 2006

Electromagnetic source localization using realistic head models

Solve the forward problem using realistic head models (BEM)



Simple Map



Source Estimate

Sensor Localization

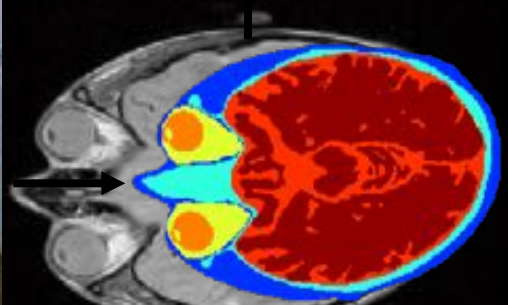
Signal Processing

Mesh generation

T1-weighted

T2-weighted

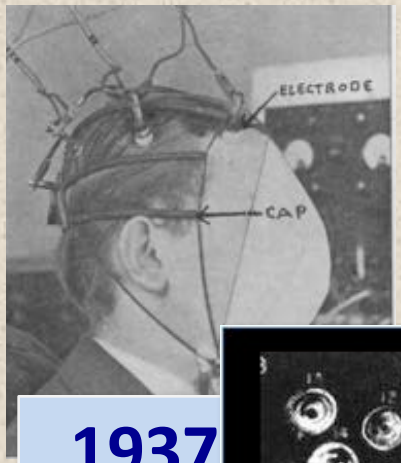
MRI



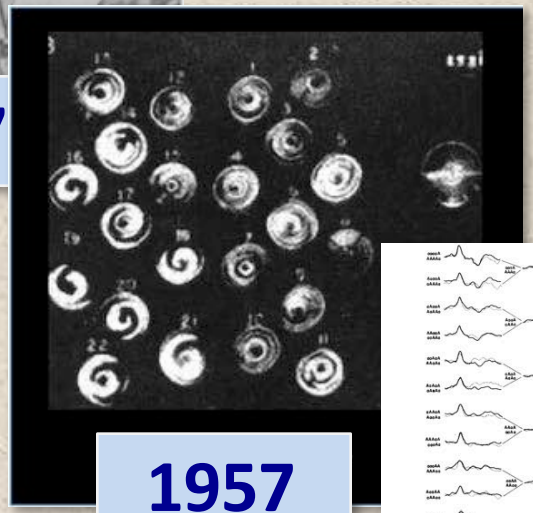
Segmentation

EEG/MEG

Development of EEG brain Imaging …

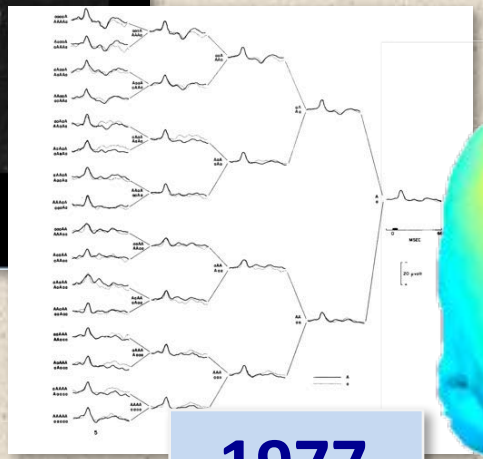


1937



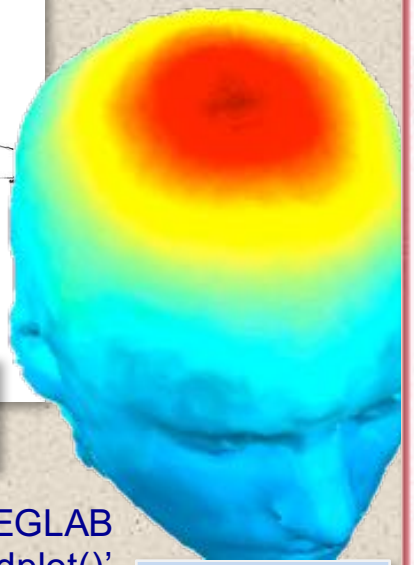
1957

Toposcope
Grey Walter



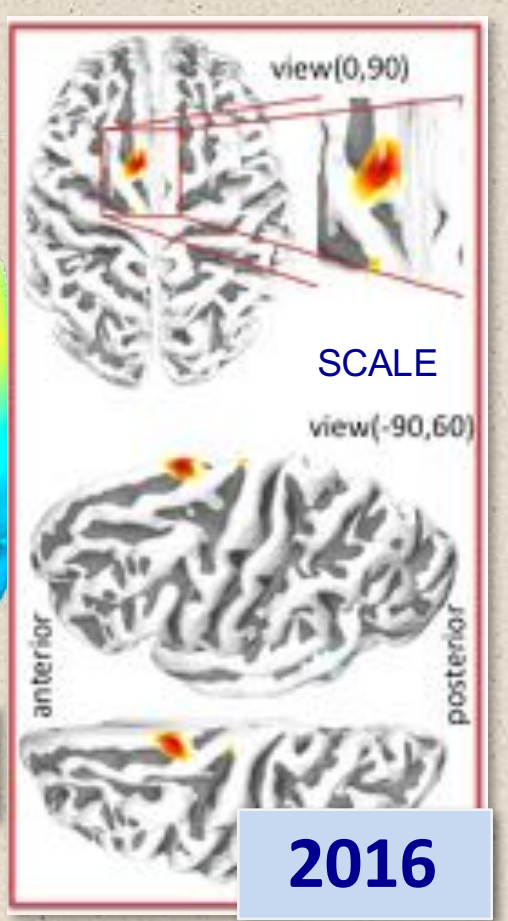
Oddball ERPs
K. Squires et al.

1977



EEGLAB
'headplot()'

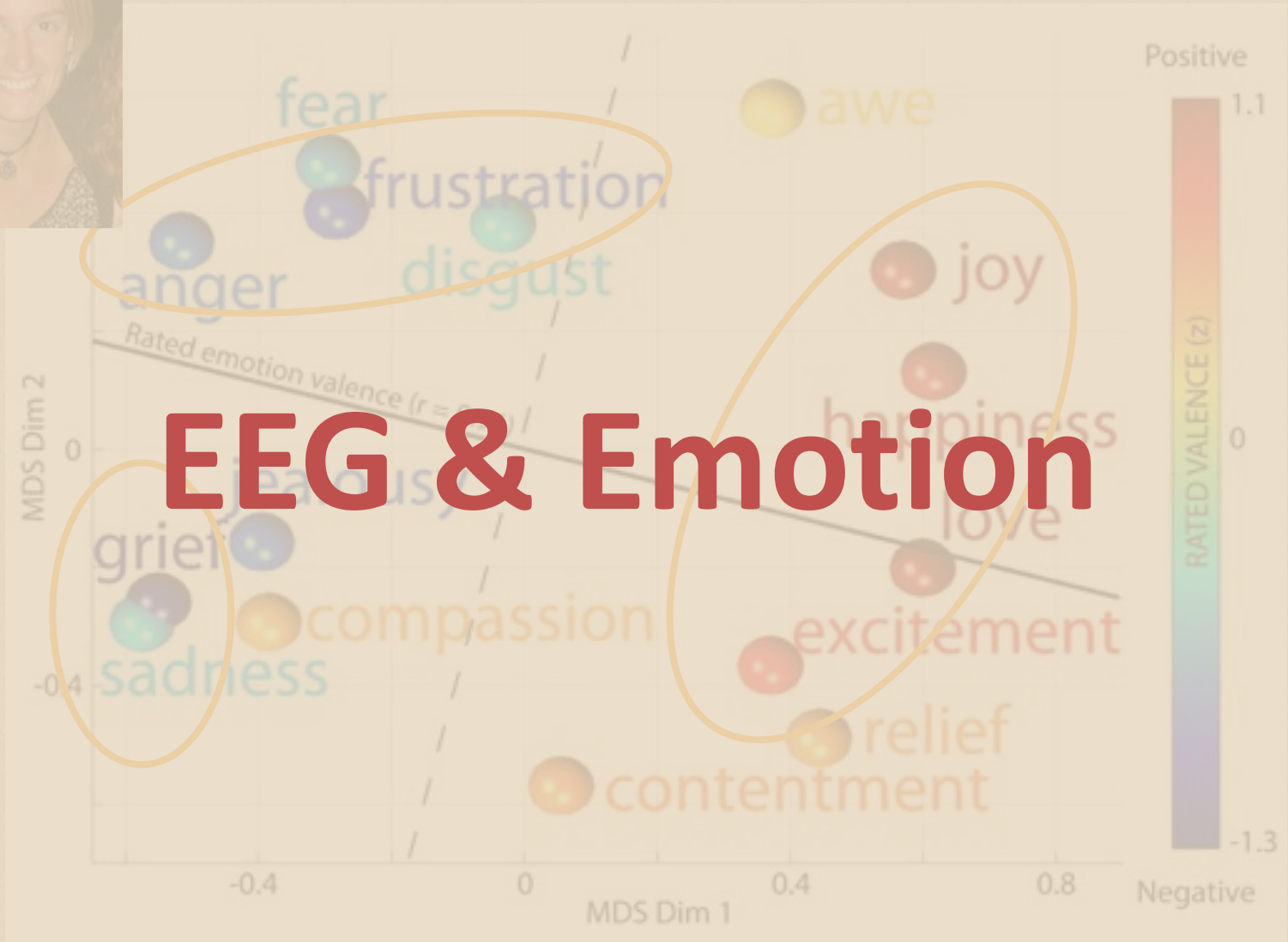
1997



2016

A. Akalin Acar et al., 2015

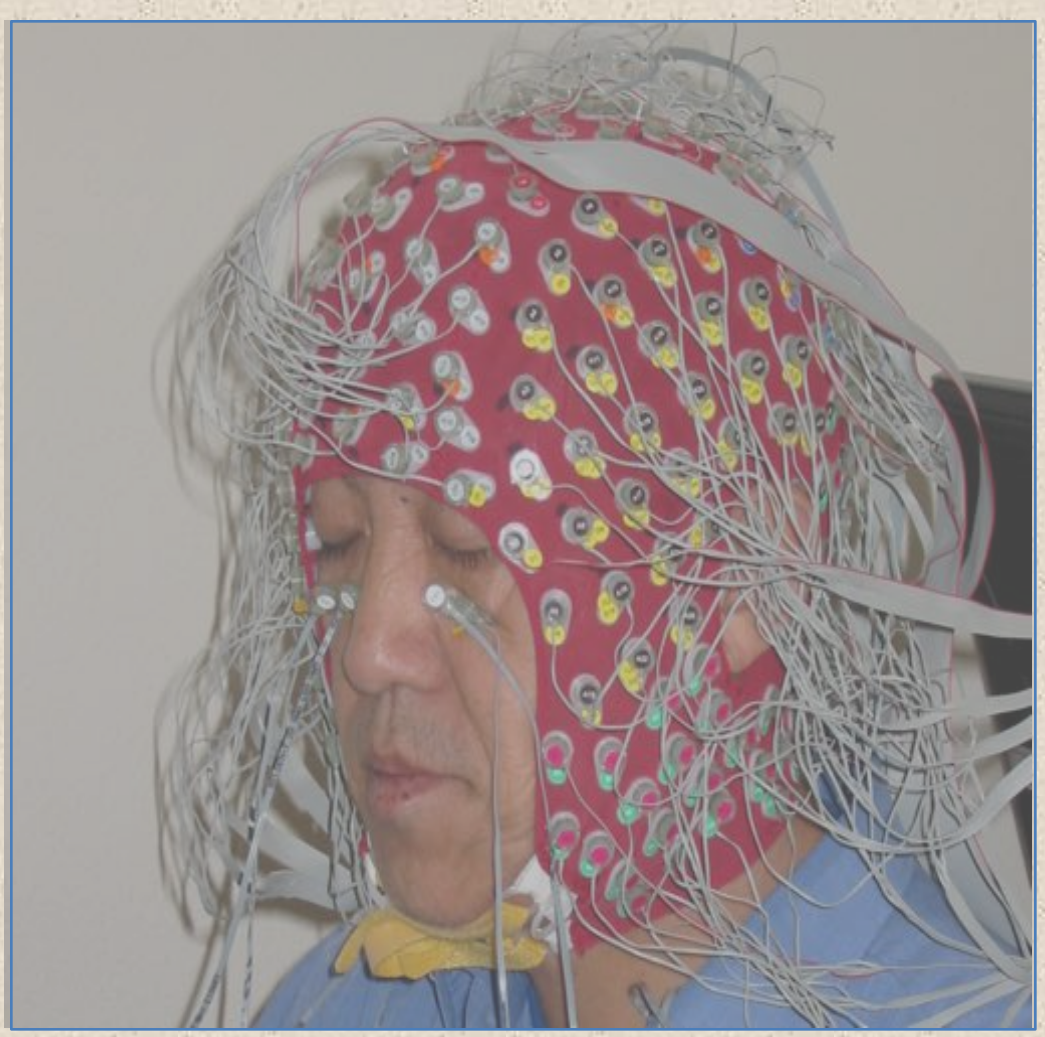
Changes in the distribution of high-frequency broadband EEG power with imagined emotion



EEG & Emotion

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

EEG Dynamics of Emotion Imagination

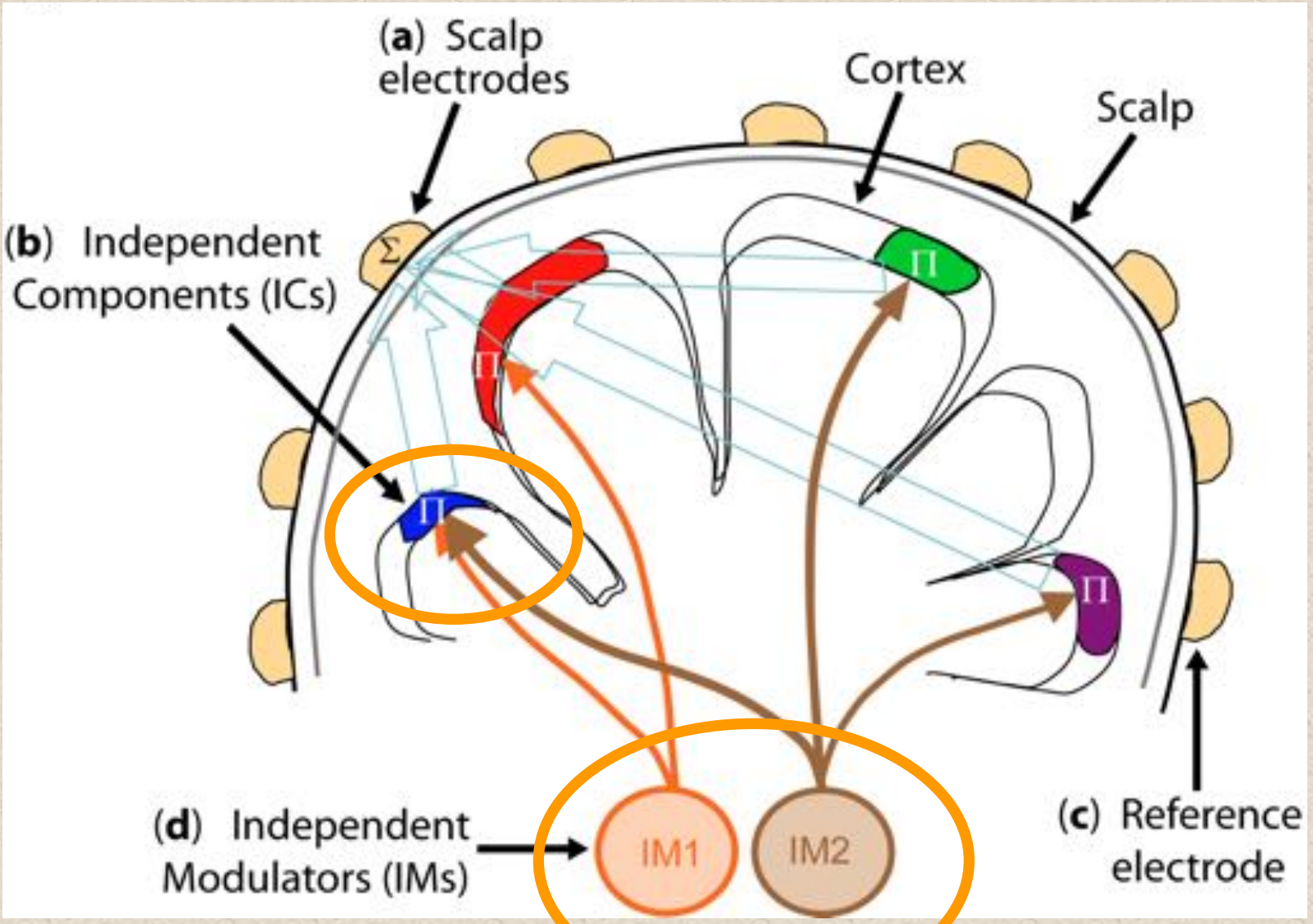


Suggest the imaginative experience of 15 emotions:

- after Helen Bonny
- relaxation
- alternate positive and negative emotions
- relaxation between emotion episodes
- obtained 1-5 min periods of eyes-closed spontaneous EEG
- 33 subjects

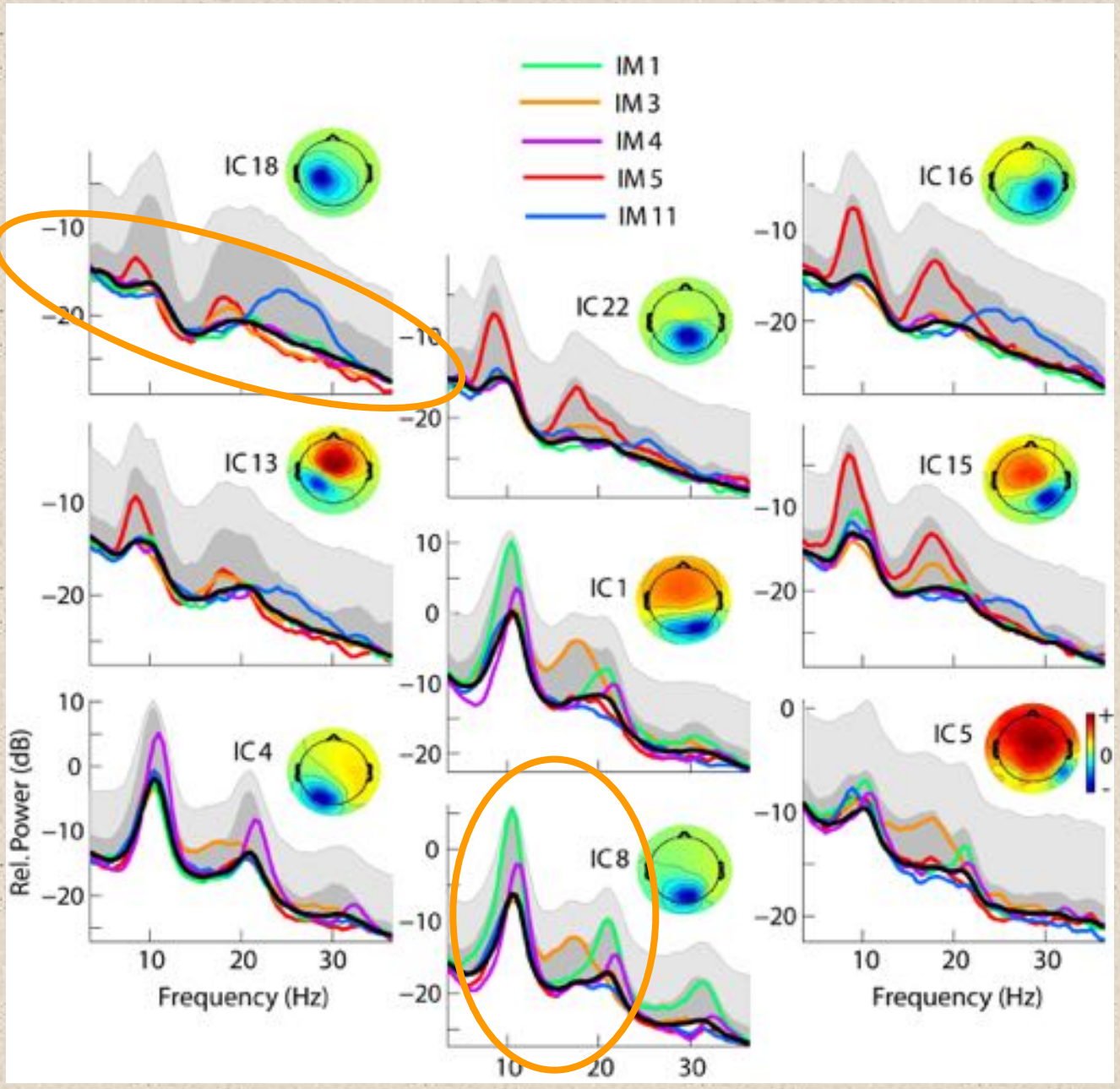
Onton & Makeig, *Frontiers in Human Neuroscience* '09

Independent Modulators

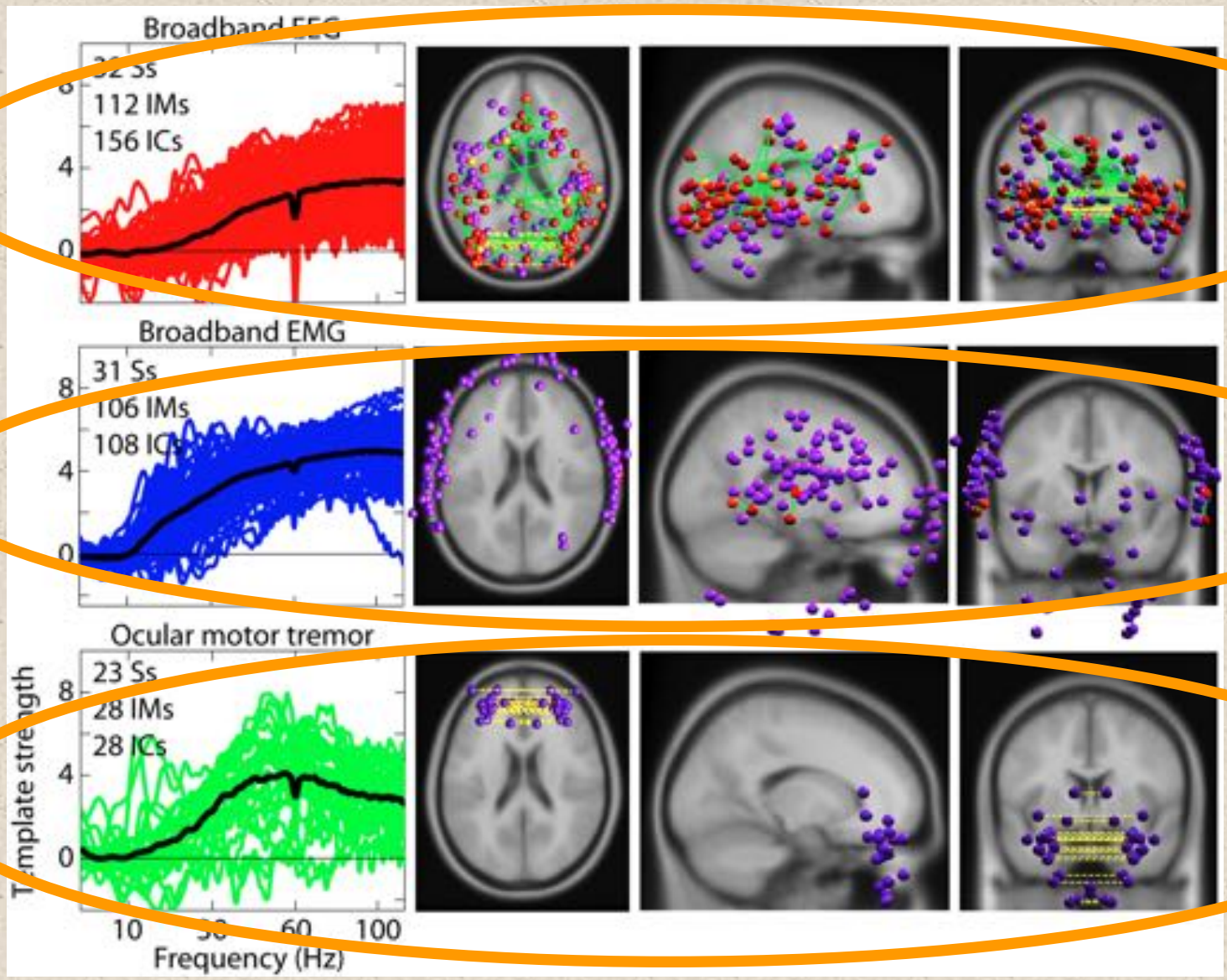


Onton & Makeig, *Frontiers in Human Neuroscience* '09

Independent Modulators

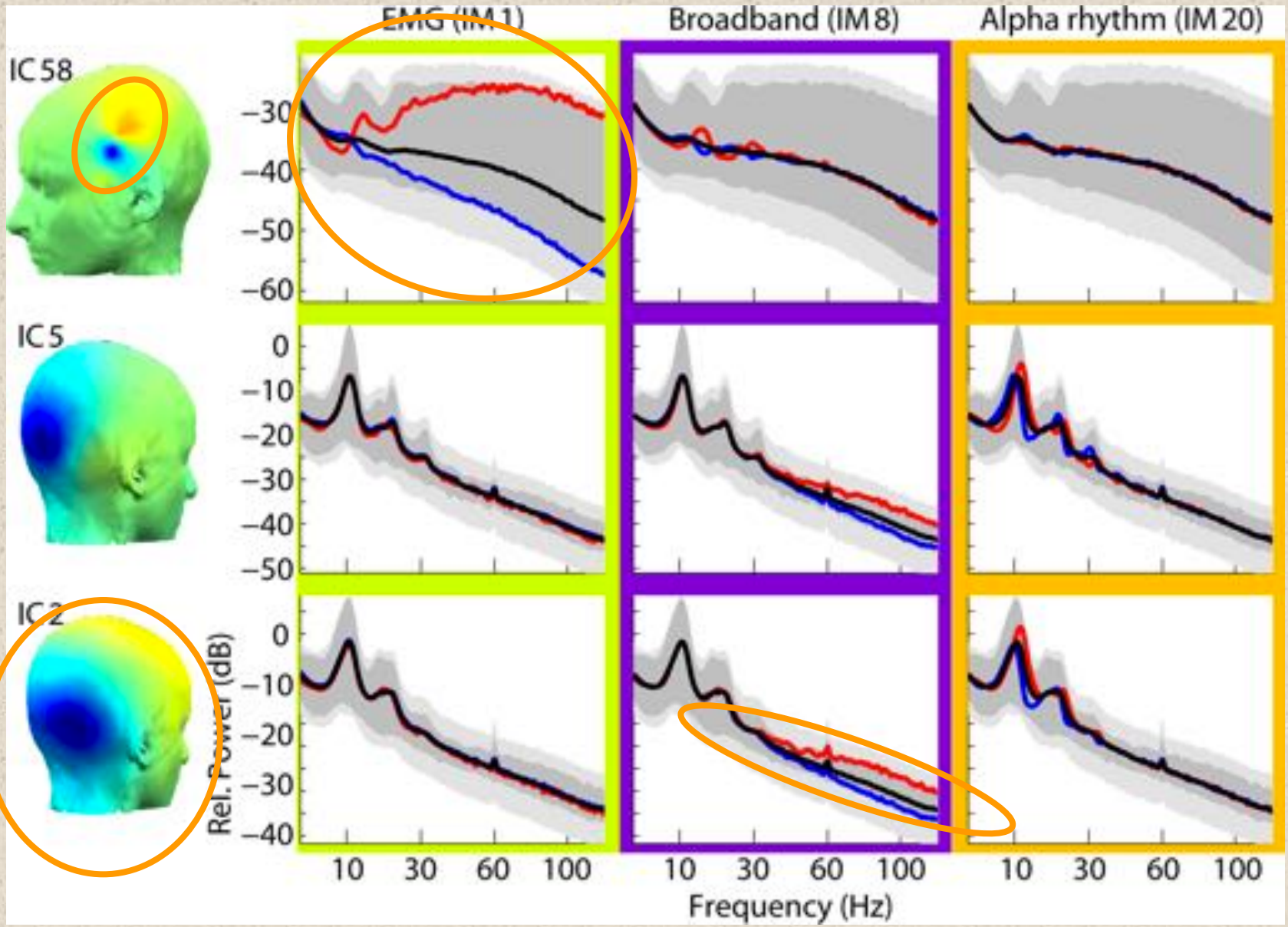


Onton & Makeig, *Frontiers in Human Neuroscience* '09



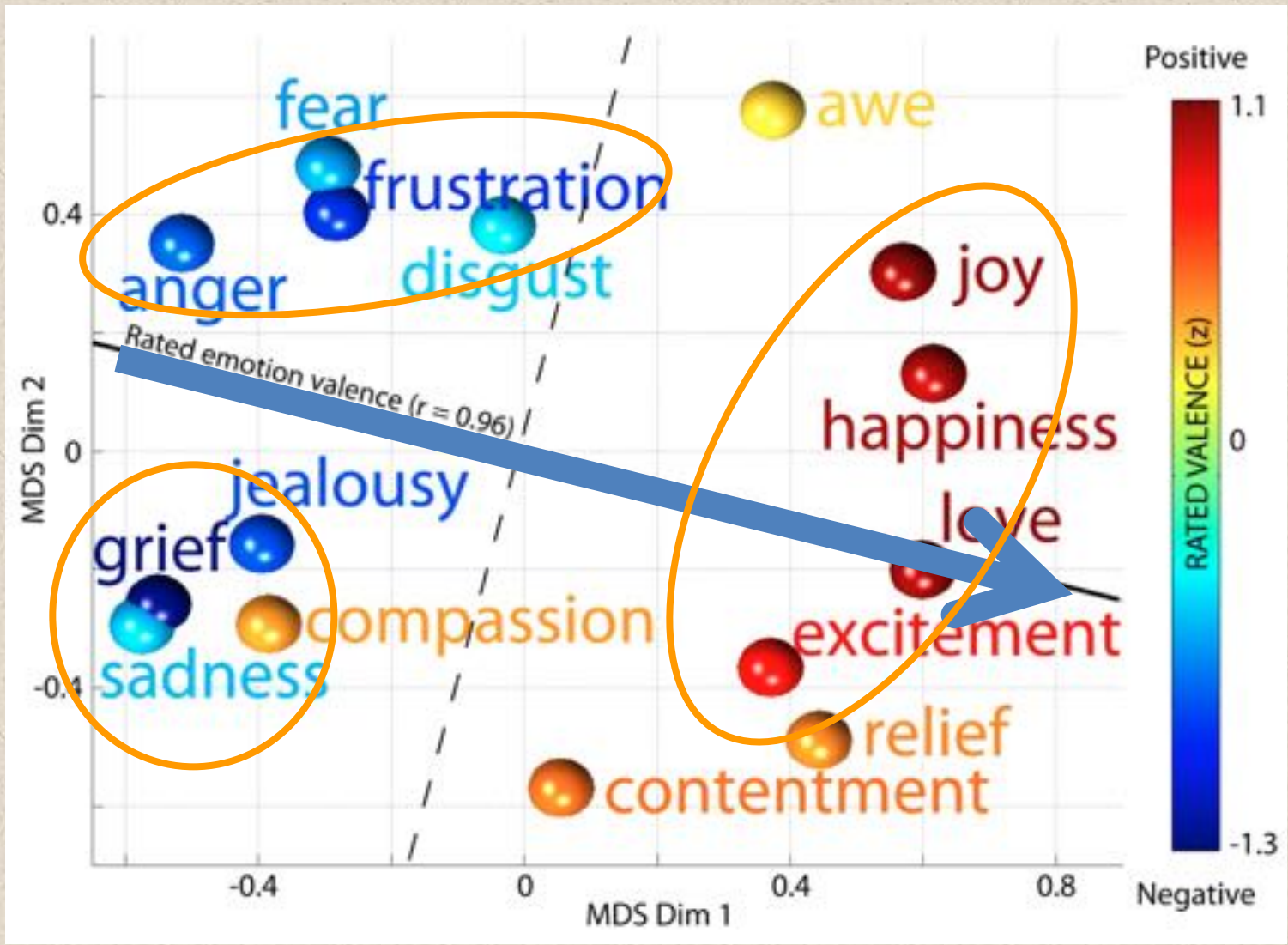
Onton & Makeig, *Frontiers in Human Neuroscience* ‘09

Independent Modulators

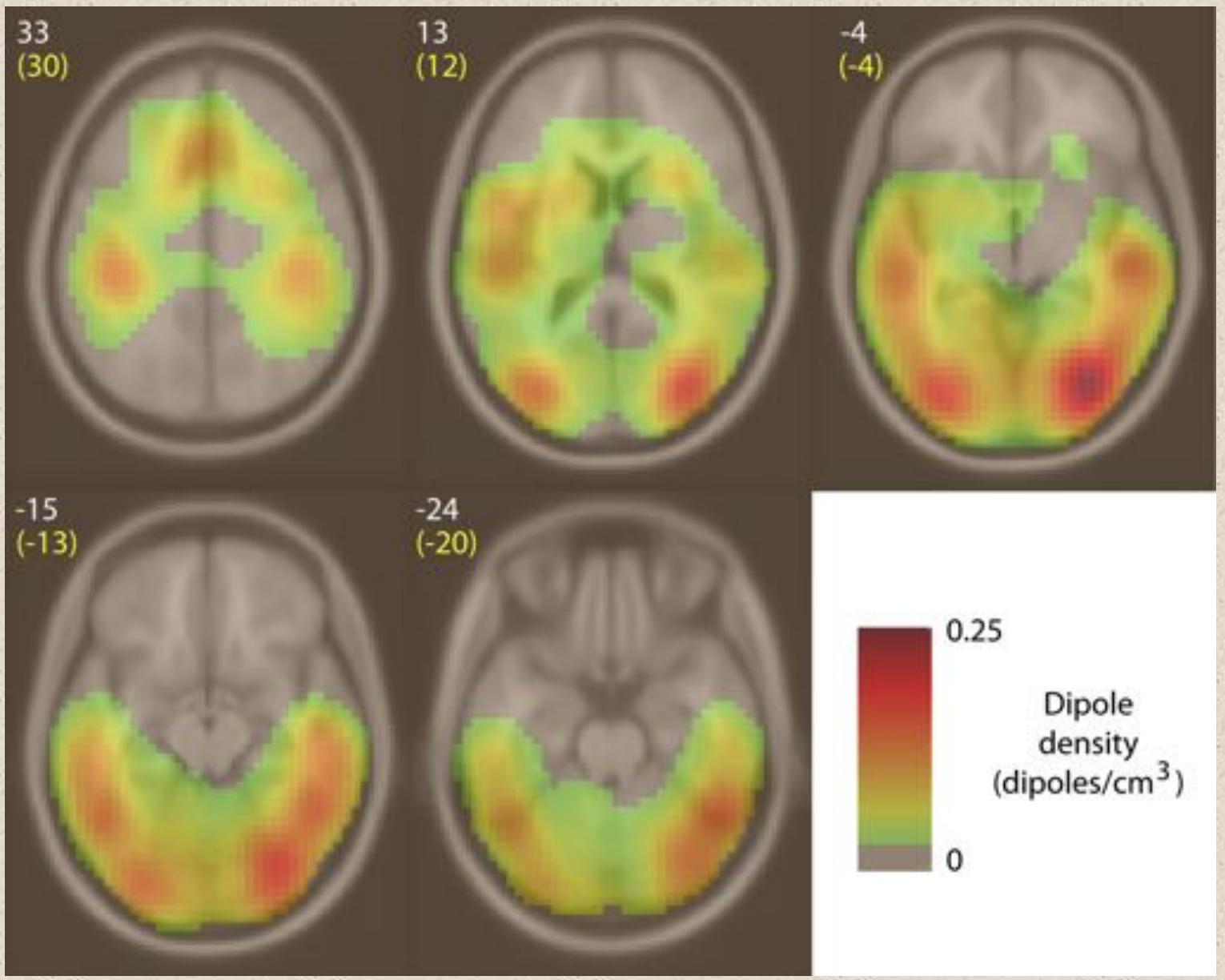


Onton & Makeig, *Frontiers in Human Neuroscience* '09

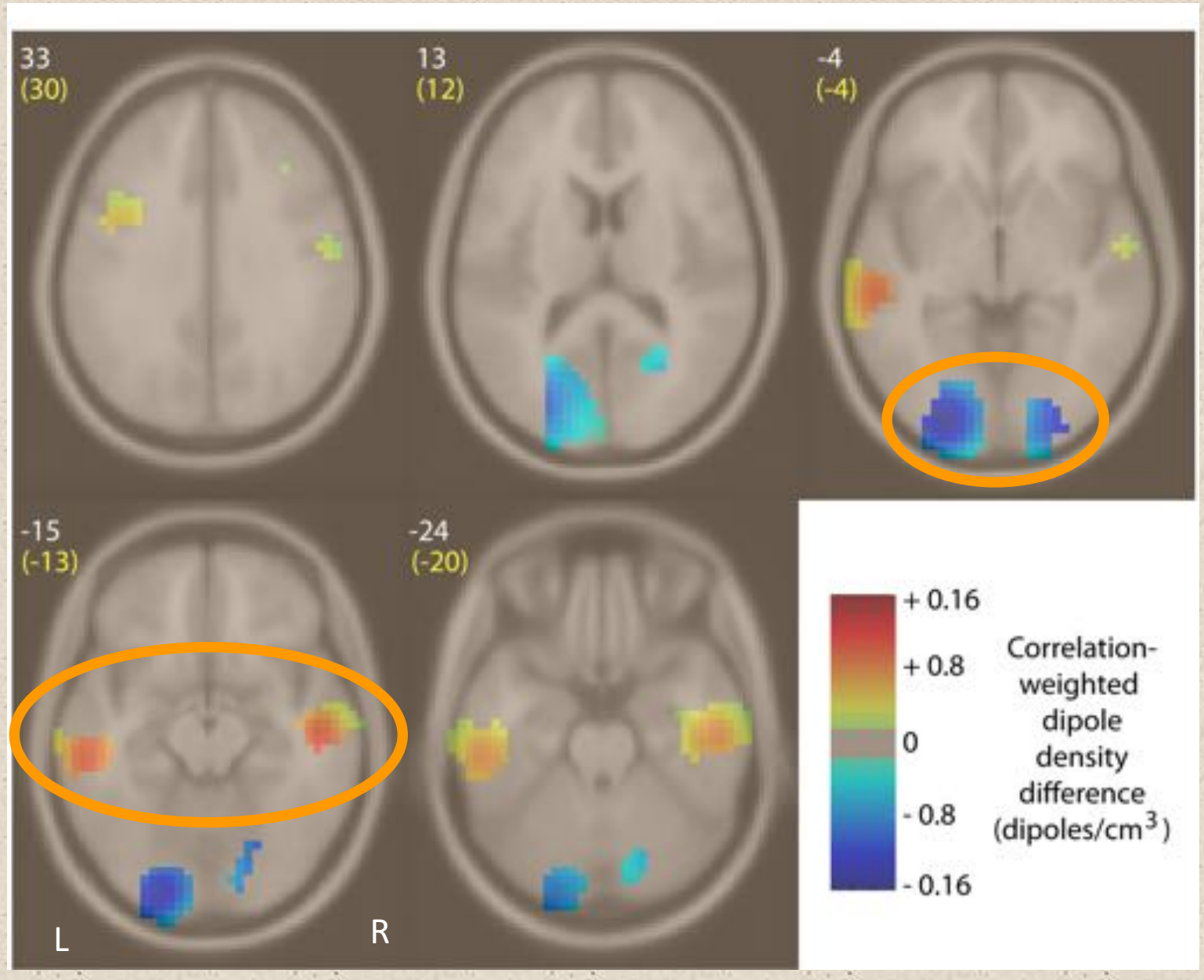
Changes in distribution of *broadband high-frequency* EEG power with imagined emotion



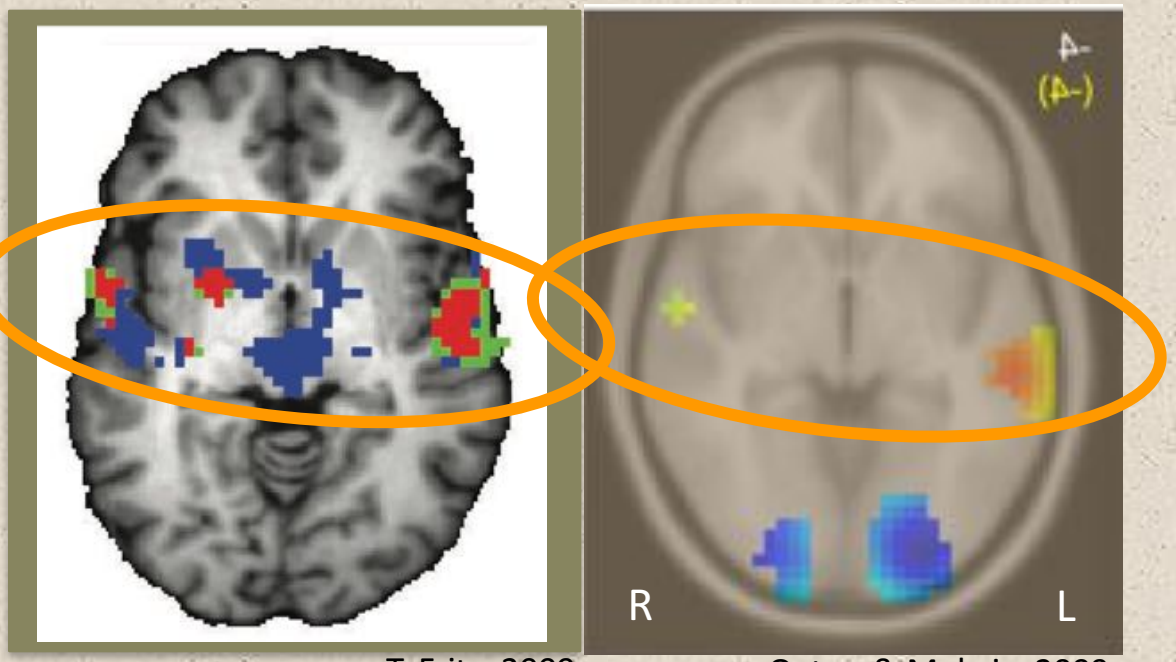
Julie Onton & Scott Makeig, *Frontiers in Human Neuroscience*, 2009



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



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



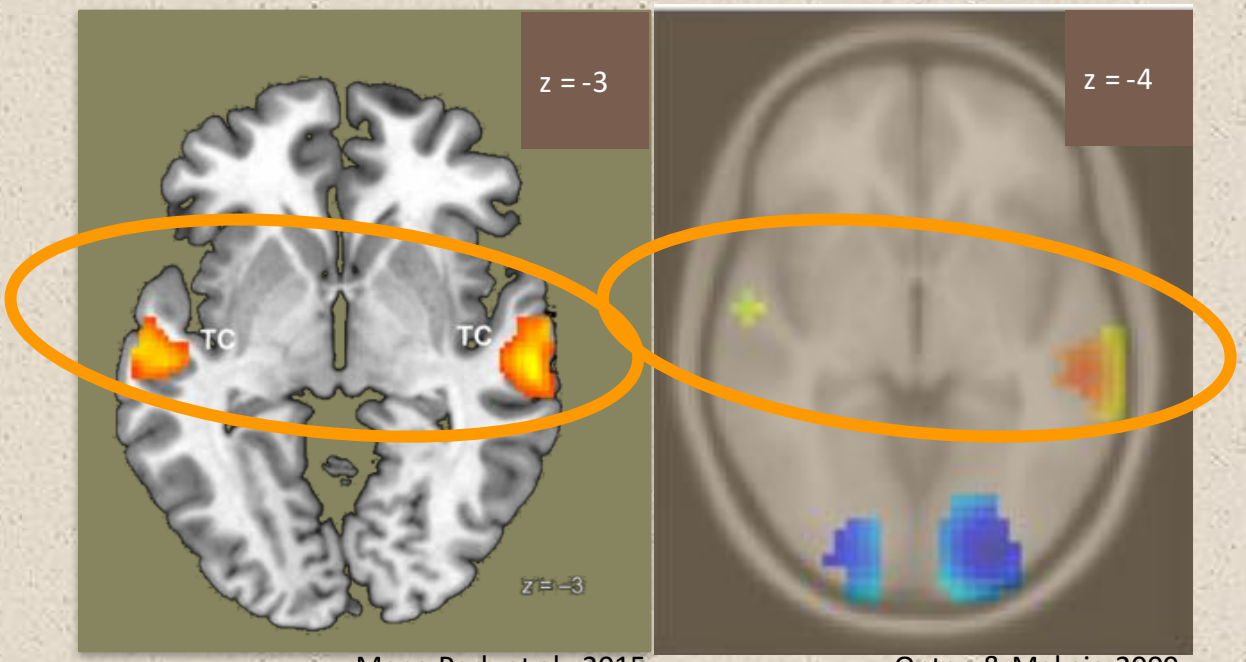
T. Fritz, 2009

Onton & Makeig, 2009

fMRI BOLD

EEG HFB

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



Mona Park et al., 2015

Onton & Makeig 2009

fMRI BOLD

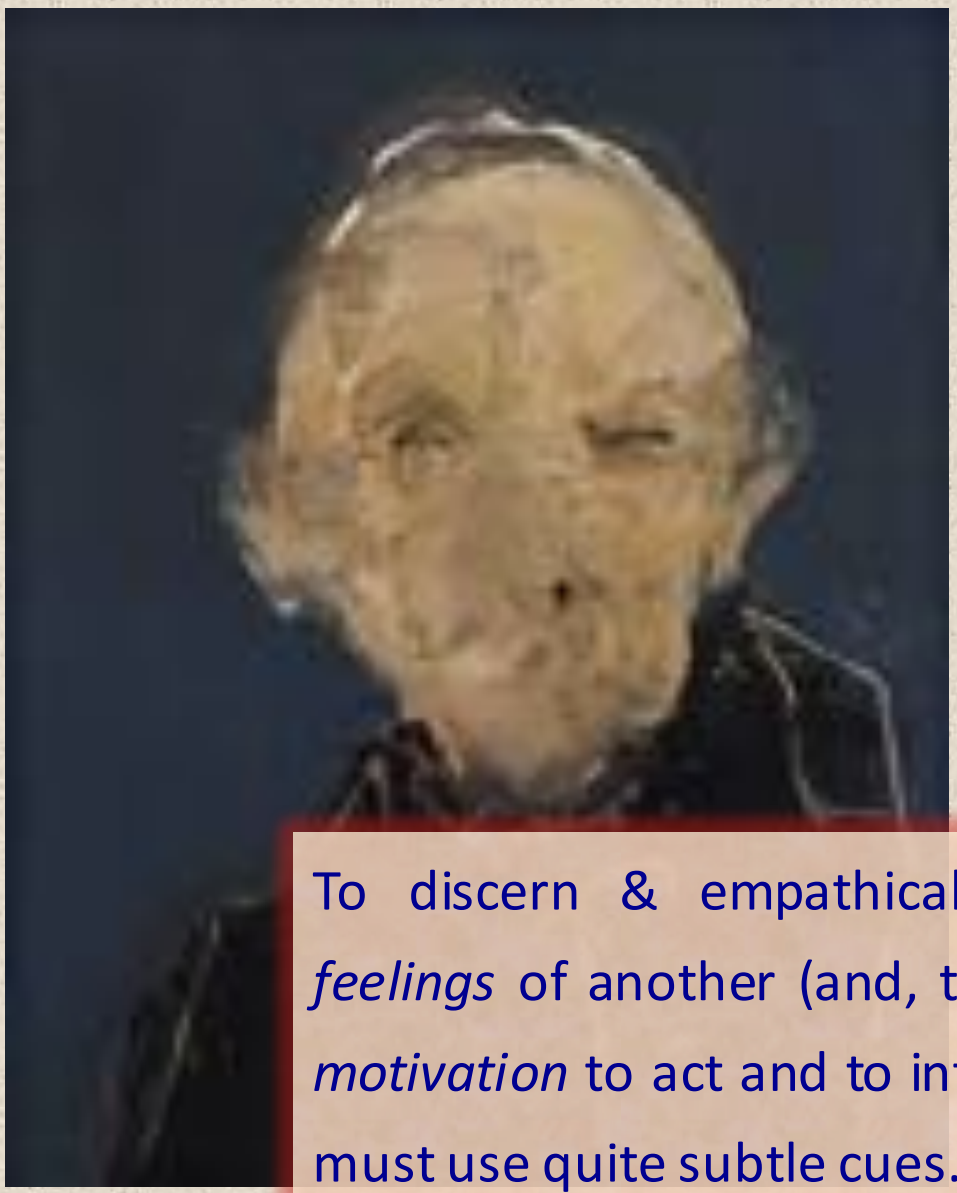
EEG HFB

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

Embodied Agency & Social Neuroscience

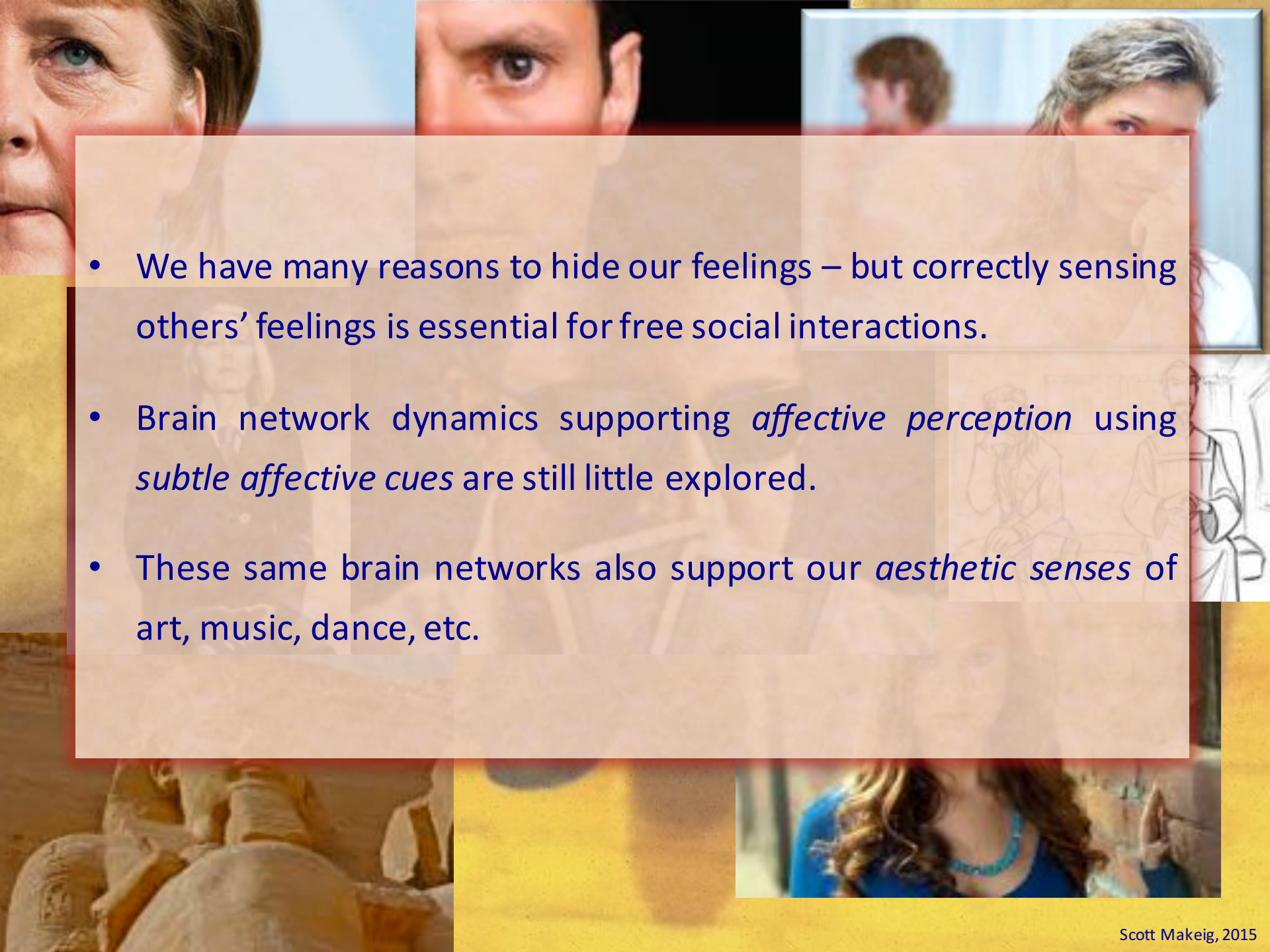
S . Makeig, 2007

‘Theory of Heart’



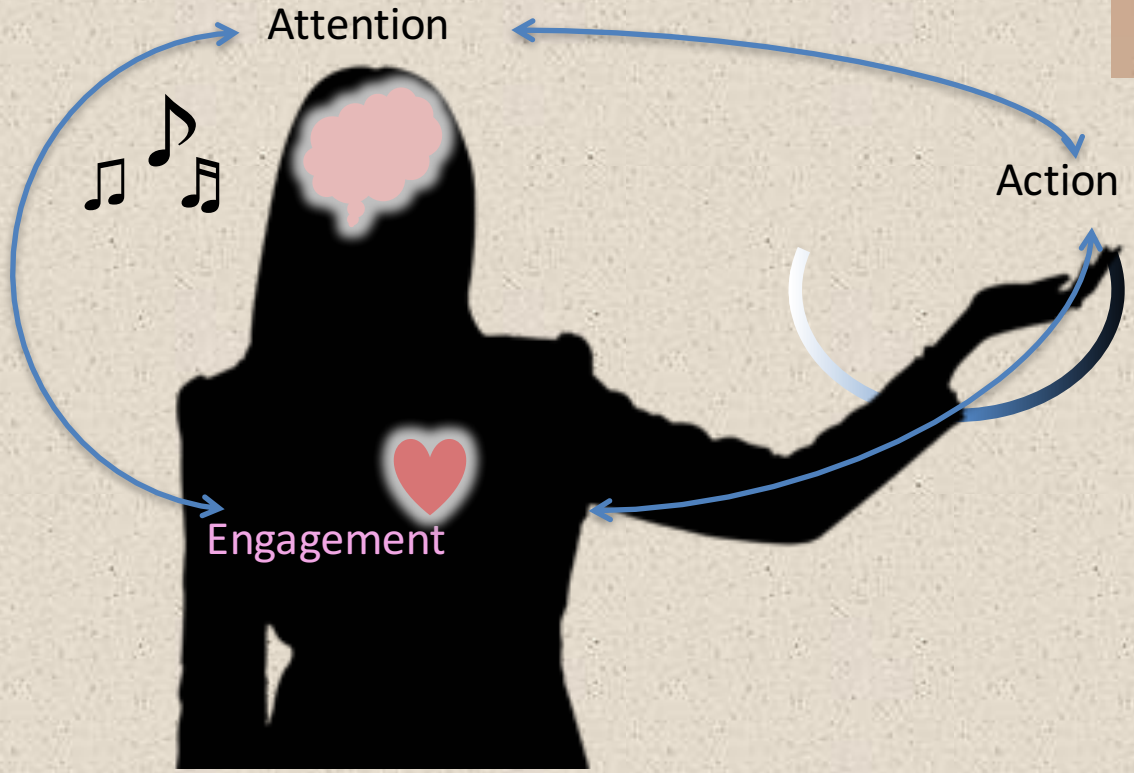
Francis Bacon

To discern & empathically experience the *feelings* of another (and, thereby, know their *motivation* to act and to interact), we typically must use quite subtle cues…



- We have many reasons to hide our feelings – but correctly sensing others' feelings is essential for free social interactions.
- Brain network dynamics supporting *affective perception* using *subtle affective cues* are still little explored.
- These same brain networks also support our *aesthetic senses* of art, music, dance, etc.

Measuring Emotional Engagement and Communication



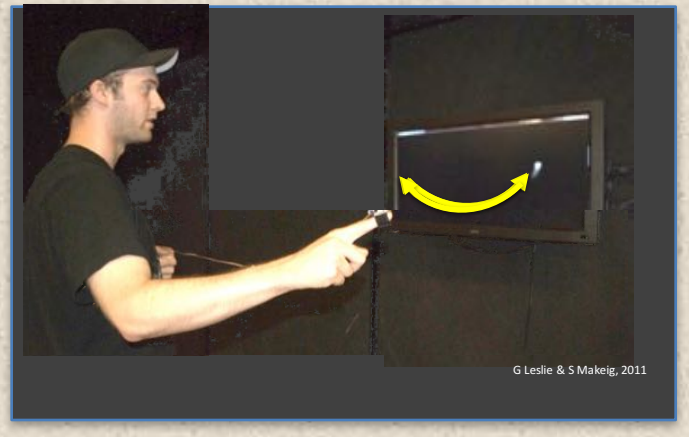
Grace Leslie & S Makeig, 2013

Expressive gesturing task

The Heart is a
Lonely Hunter (1968)

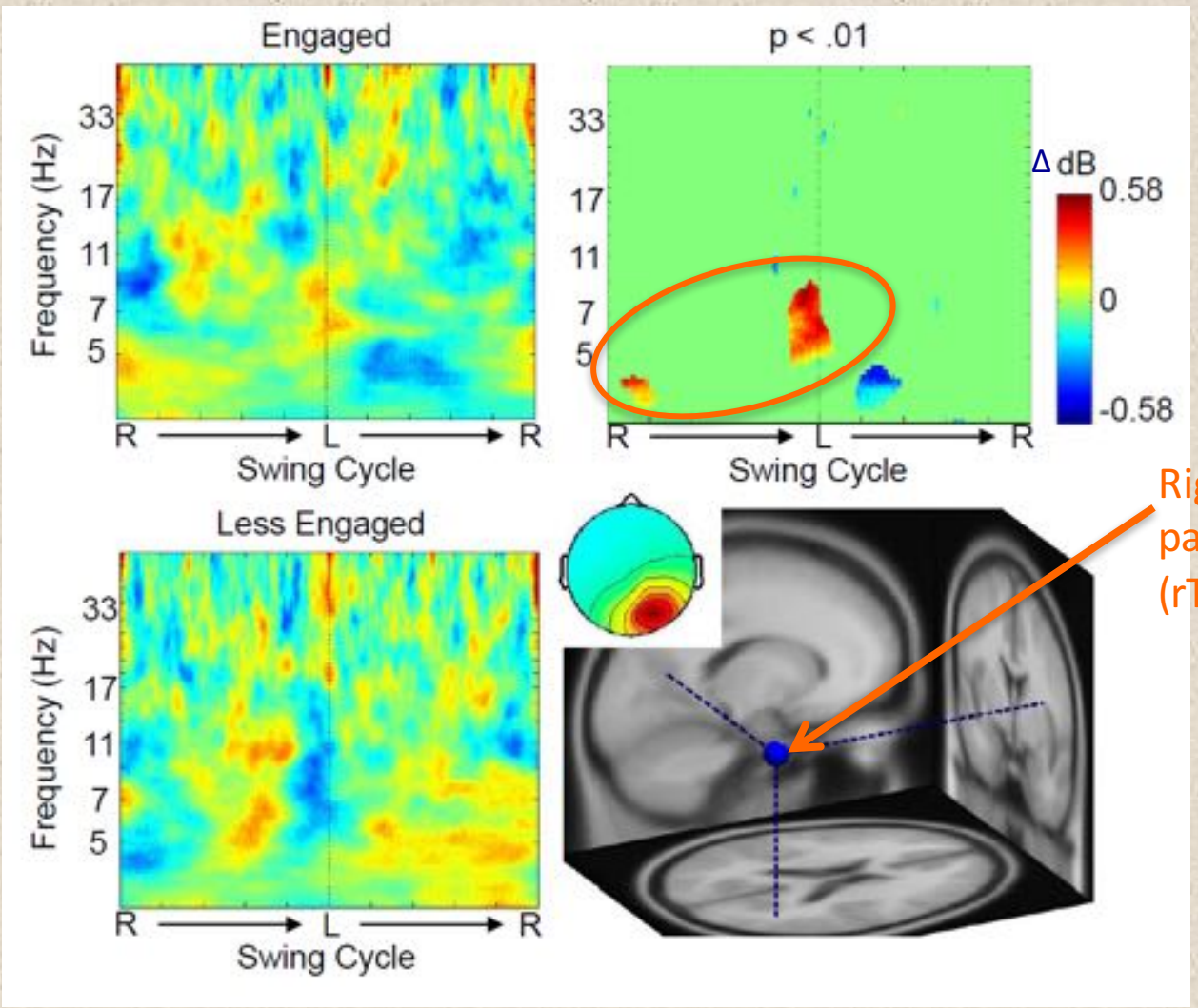
Two conditions:
- **Fully engaged**
- **Less engaged**

Conducting Experiment (2013)



Grace Leslie & S Makeig, 2013

EEG Result: Full affective engagement

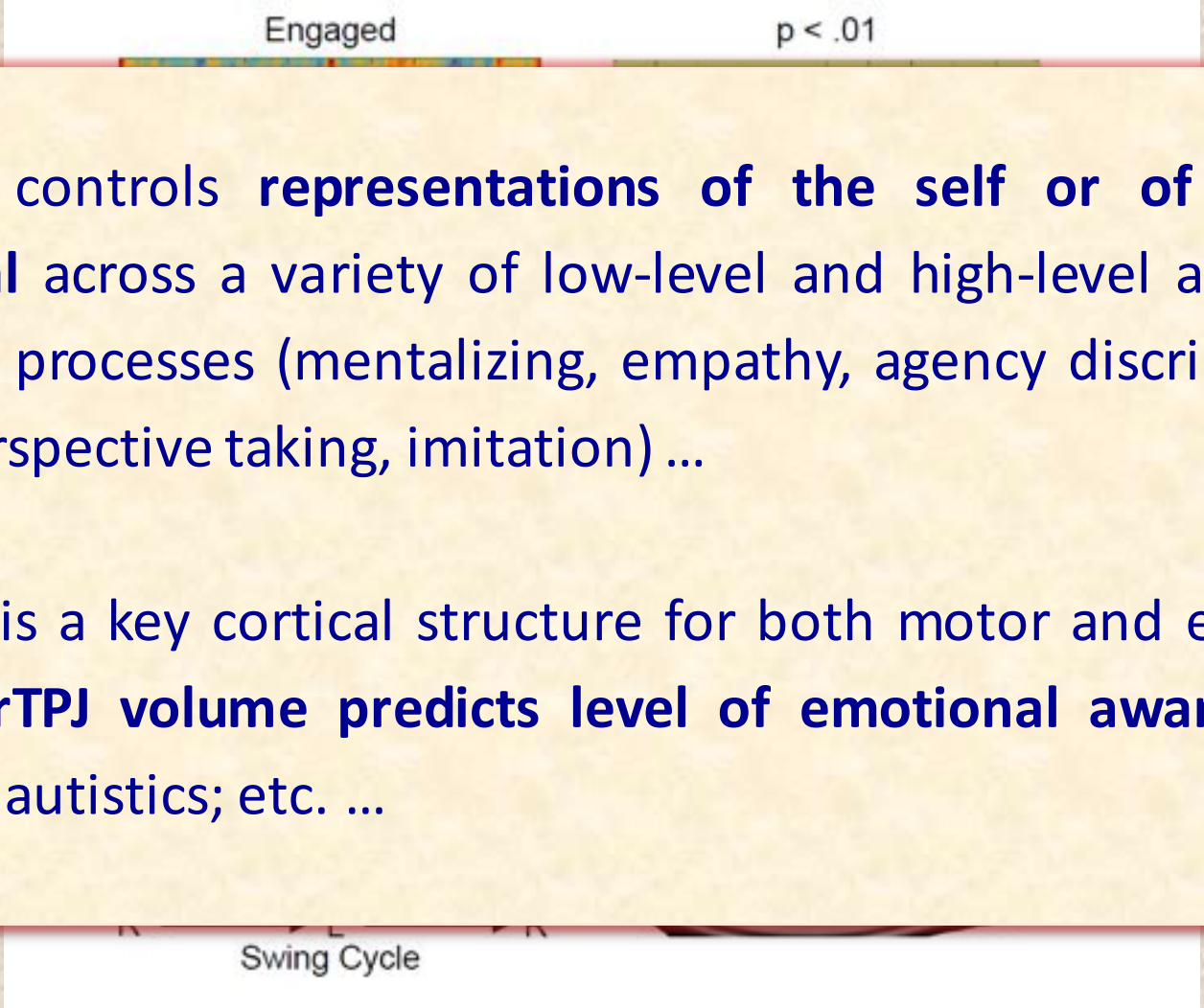


Frequency (Hz)

Swing Cycle (%)

Grace Leslie & S Makeig, 2014

EEG Result: Full affective engagement



The TPJ controls **representations of the self or of another individual** across a variety of low-level and high-level and socio-cognitive processes (mentalizing, empathy, agency discrimination, visual perspective taking, imitation) …

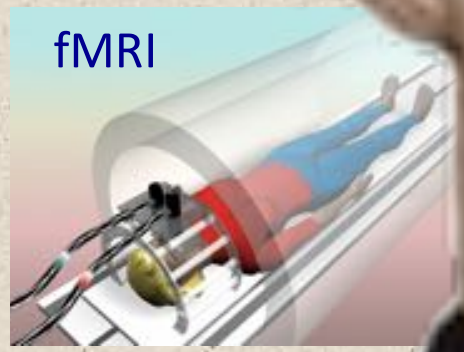
The rTPJ is a key cortical structure for both motor and emotional control; **rTPJ volume predicts level of emotional awareness of others** in autistics; etc. …

Swing Cycle (%)

Grace Leslie & S Makeig, 2014

Brain imaging during motor behavior?

- Nearly all brain imaging studies (MEG, PET, fMRI, and EEG) are conducted in rigidly stati seated or prone positions with only the most minimal ger movem allowed.



Why?

- In all modalities but E ors are **heavy**.
- Muscle and movements co ('noise') signals.

- **But this limitation is highly artificial.** Nearly all our life olves *active movements* and *interactions* within a 3-D environment.
- → **Brain activity during free movement in 3-D space**

has never been observed or modeled!

Mobile Brain/Body Imaging (MoBI)

1. Record simultaneously, during naturally motivated action & interaction,

   What the brain does (high-density EEG)

   What the brain experiences (sensory scene recording)

   What the brain organizes (body & eye movements, psychophysiology)

2. Then –

   Use evolving machine learning methods

   to find, model, and measure

   non-stationary (context- and intention-related)

   functional relationships among these data modalities.

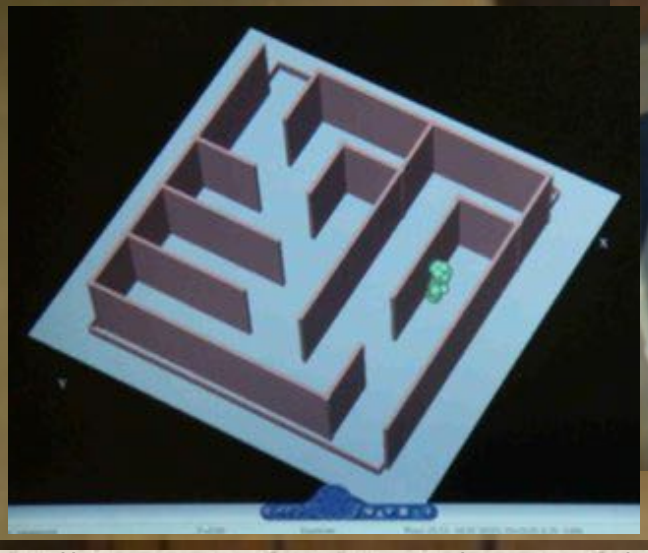
Scott Makeig, 2011

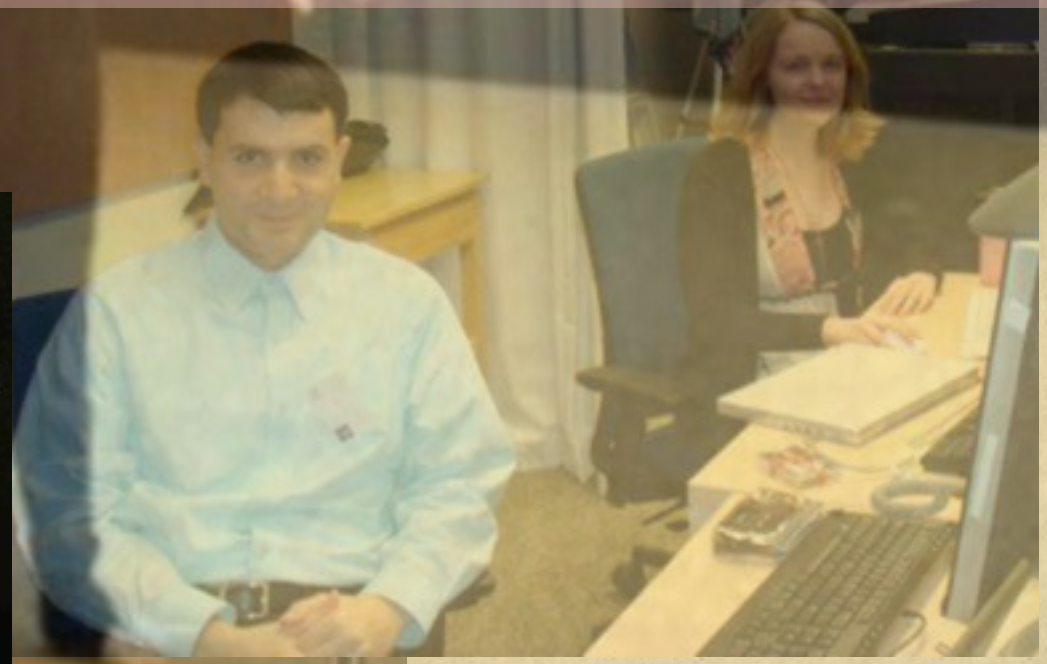
MoBI Lab at SCCN, UCSD

Lab Streaming Layer (LSL) software framework for synchronous multi-stream, multi-platform recording and feedback – freely available on *github.com*

XDF multimodal file format (*github*)

SNAP environment for simple/complex exp. control



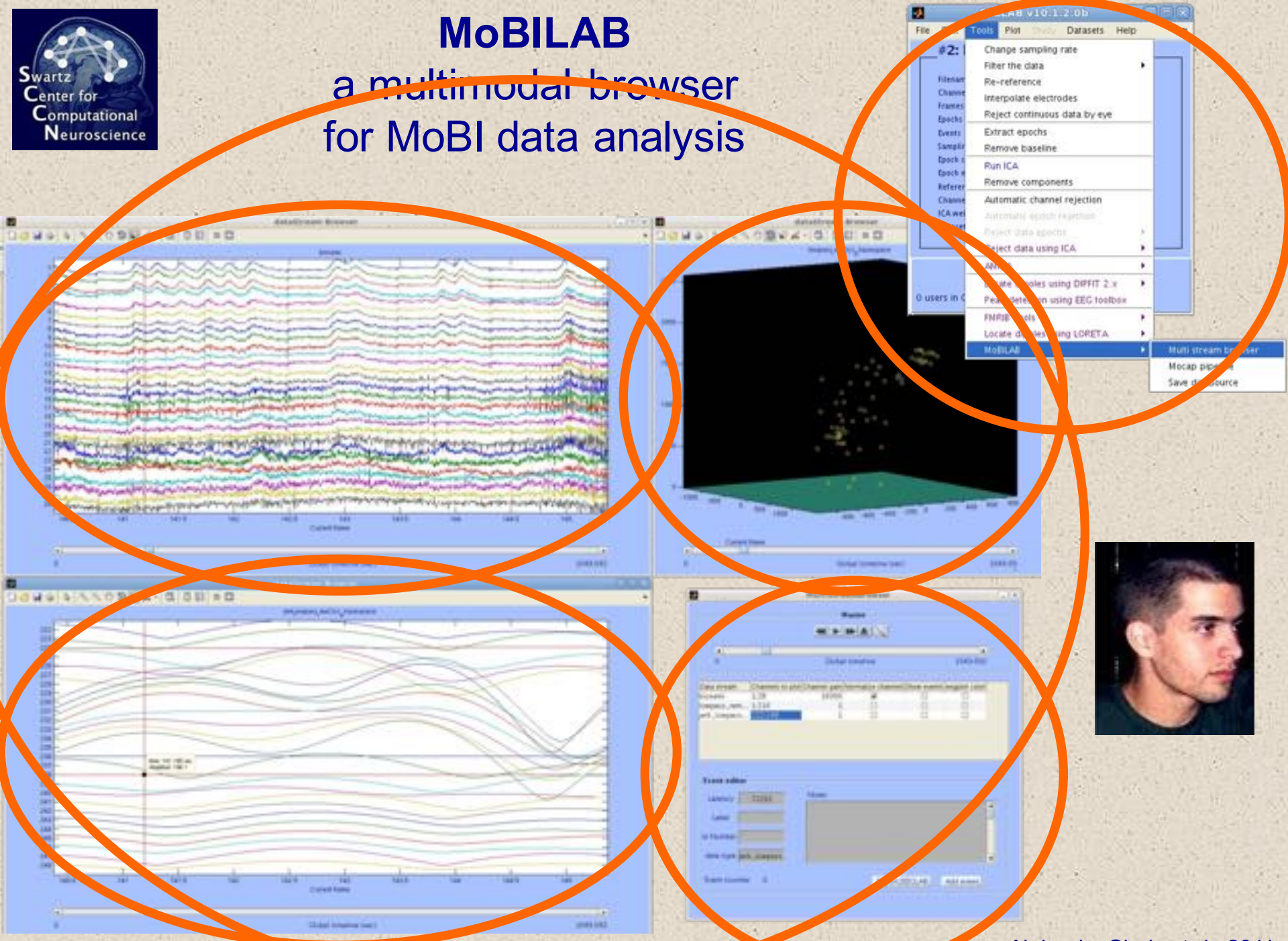


http://thesciencenetwork.org/programs/inc-sccn-open-house/inc-sccn-open-house-hi-lite-reel

MoBILAB

a multimodal browser for MoBI data analysis

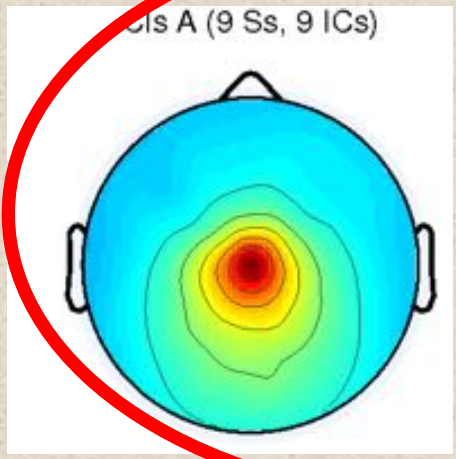
Swartz Center for Computational Neuroscience

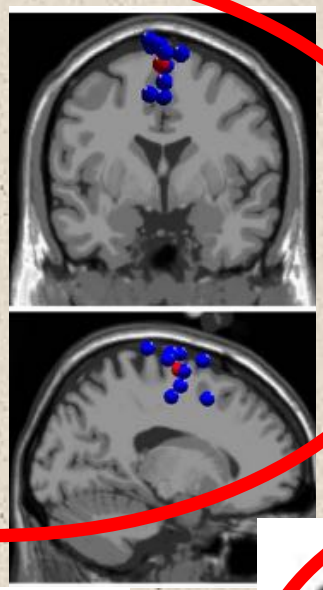


Alejandro Ojeda et al., 2011

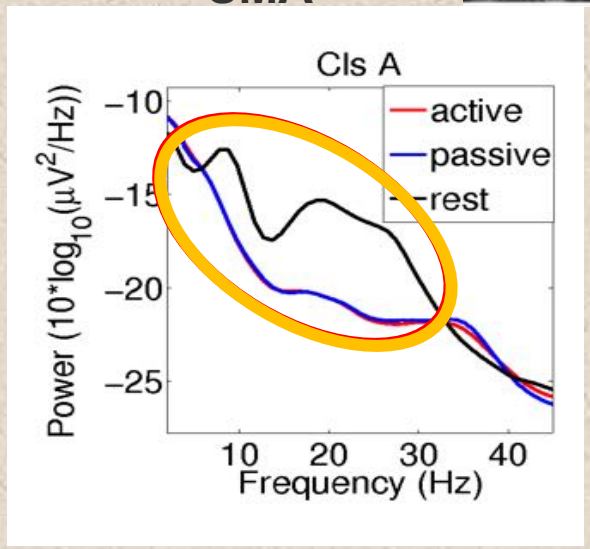
Imaging Natural Cognition with MoBI

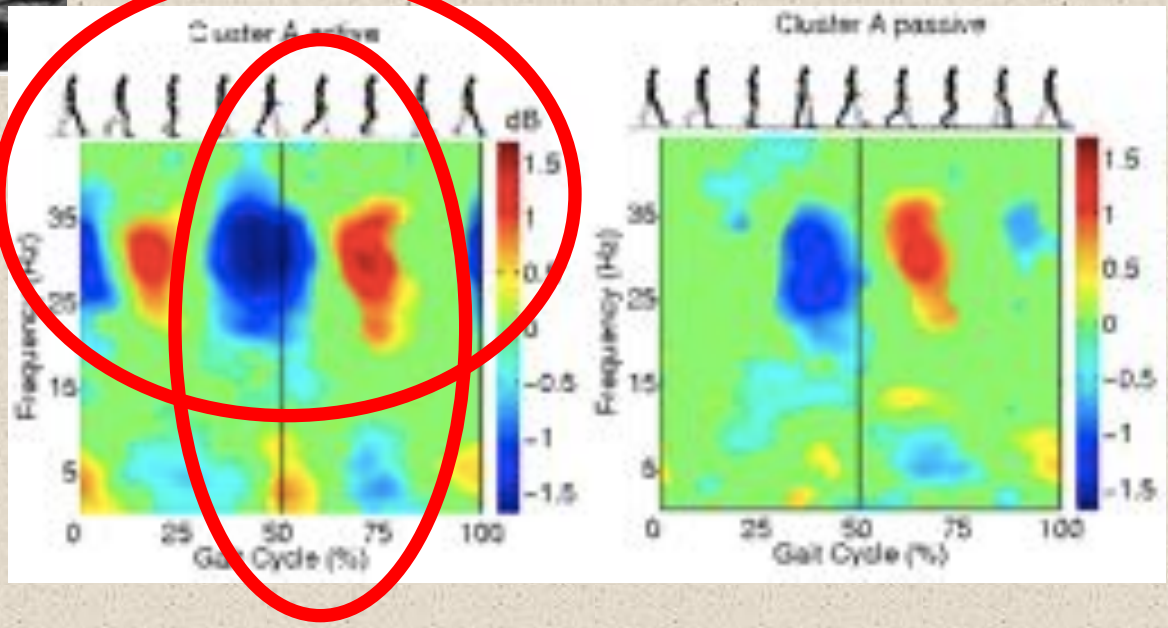
Walking modulates midline (leg) sensorimotor rhythms





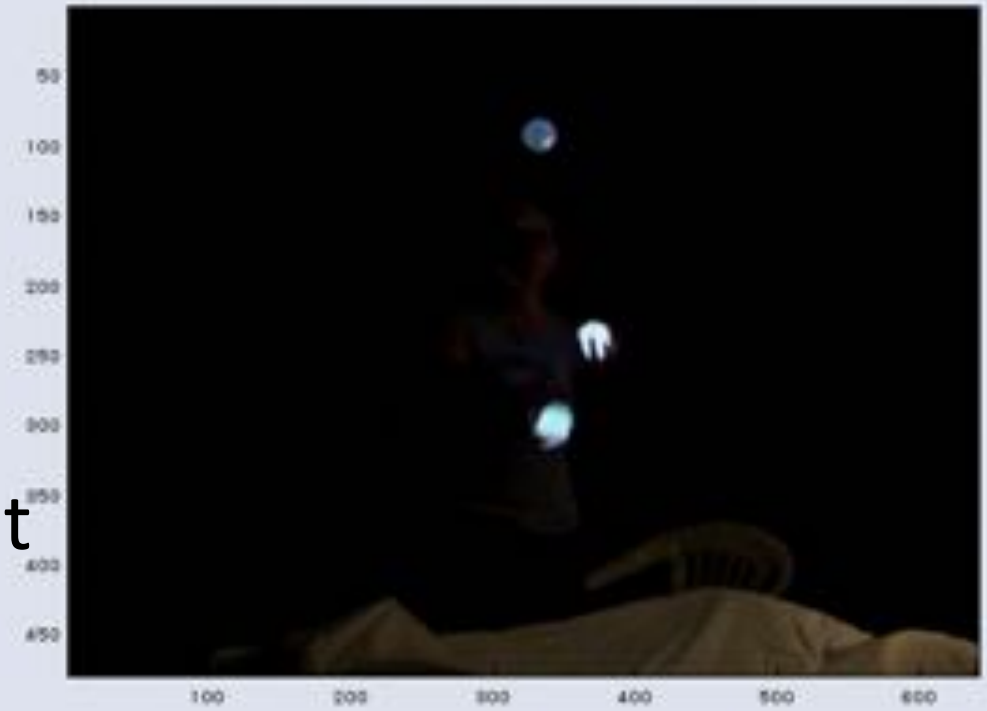
SMA

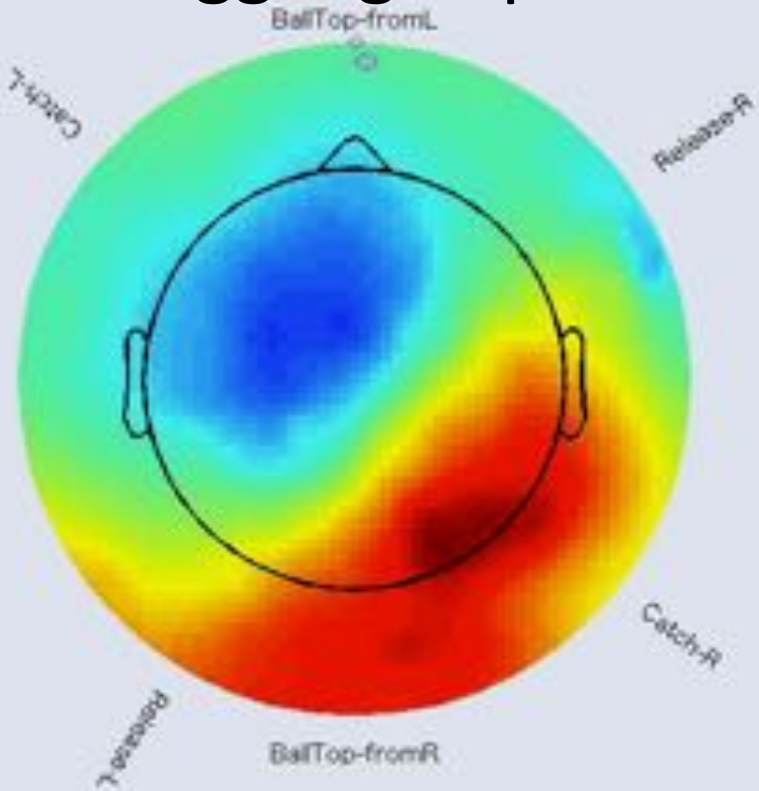


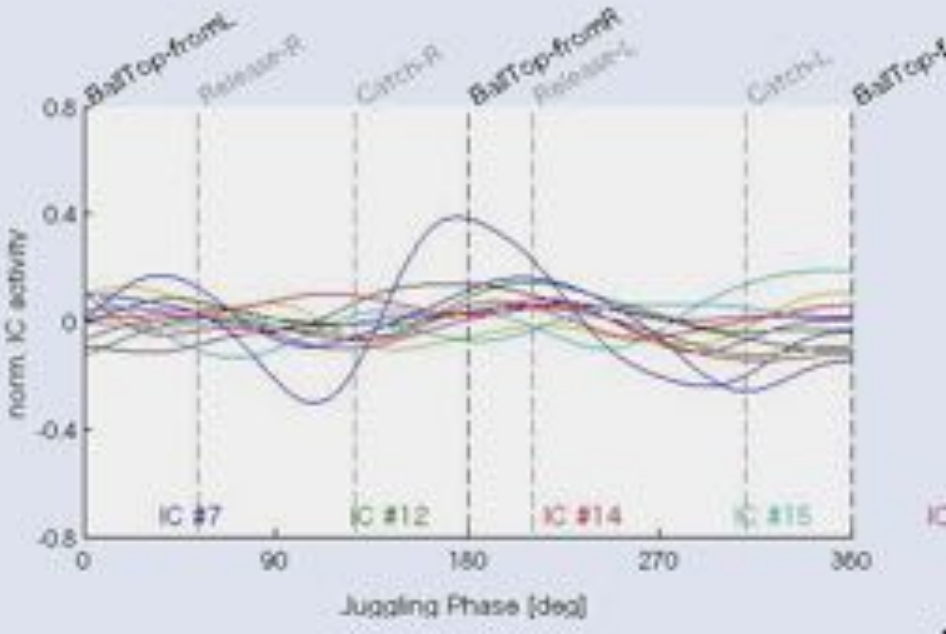


Wagner et al., *Neuroimage*, 2012

MoBI Juggling Experiment

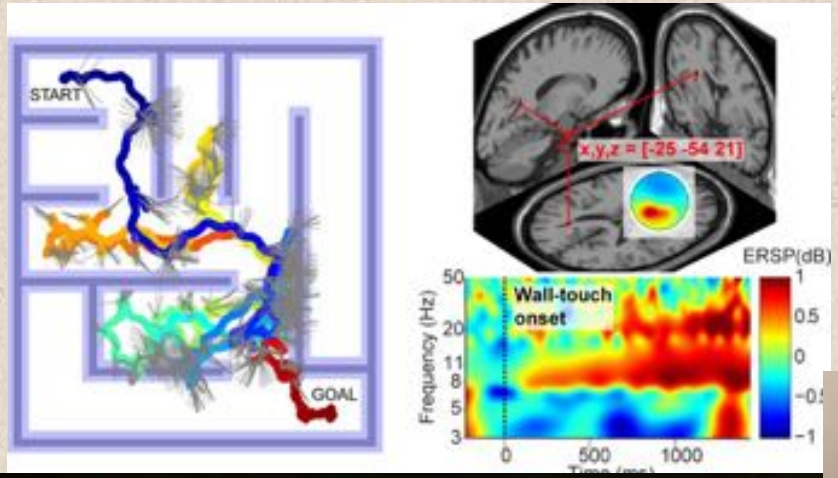


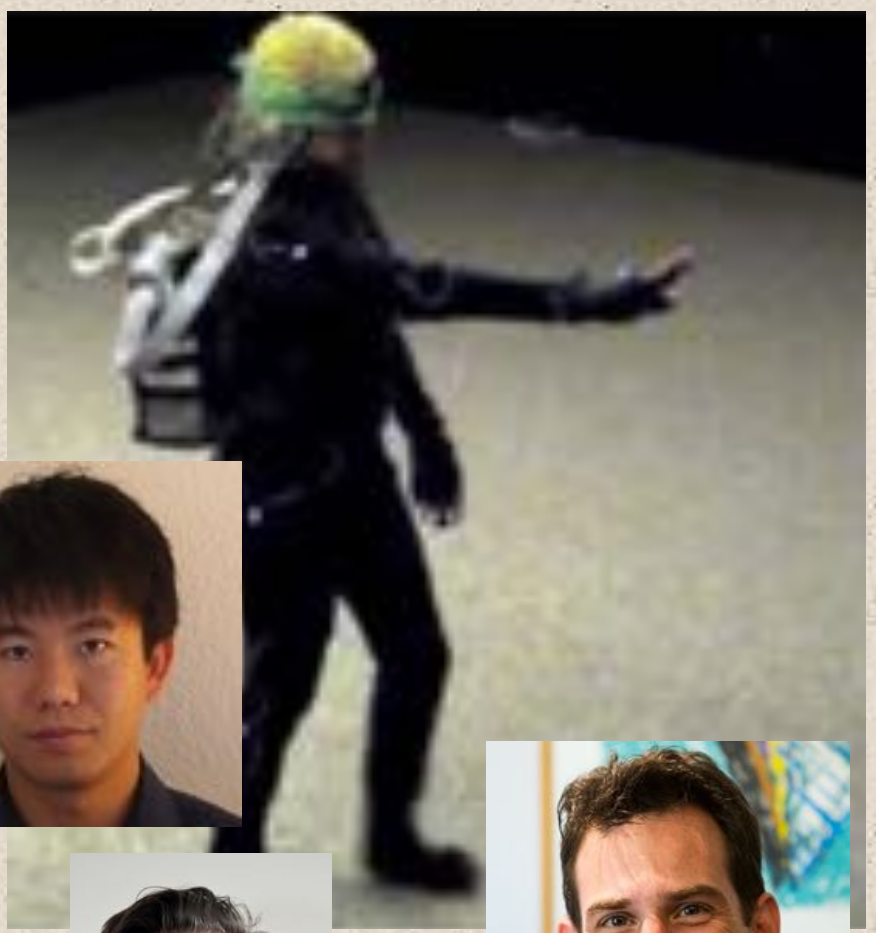


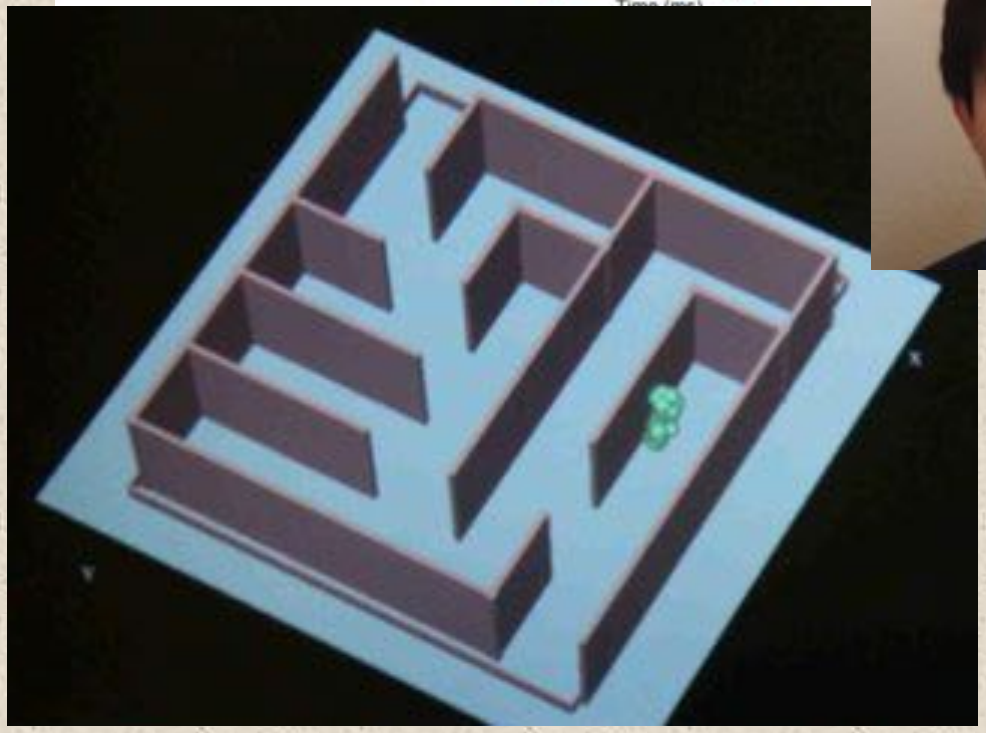


Hiroyuke Kambara, 2016

The Audio Maze







J. Iversen, M. Miyakoshi, K. Gramann, S. Makeig, 2016

Development of Shared Attention –
A Mother and Child MoBI Experiment

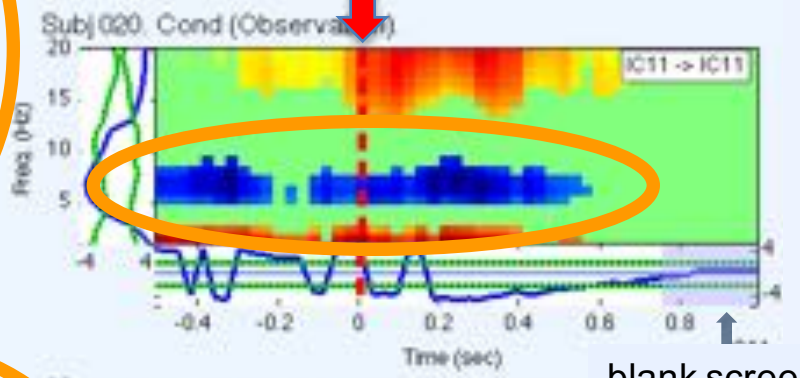
Imaging Social Interactions

Gedeon Deak et al., 2011

Gedeon Deak et al., 2011

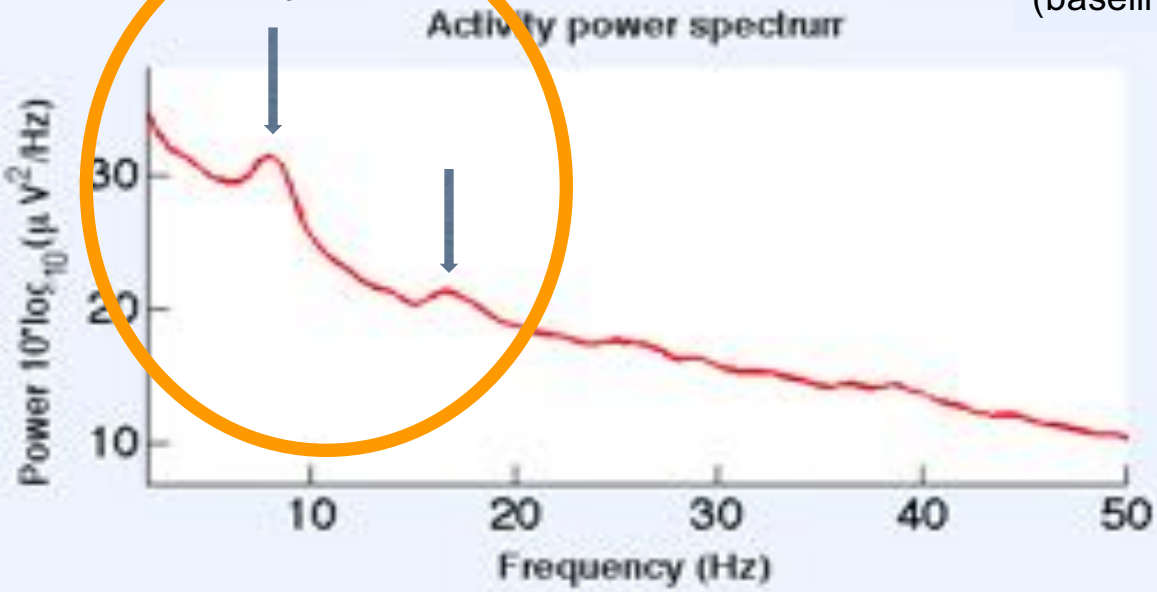
3-yr old child – Reward Observation

He watches Mom pop the bubble!

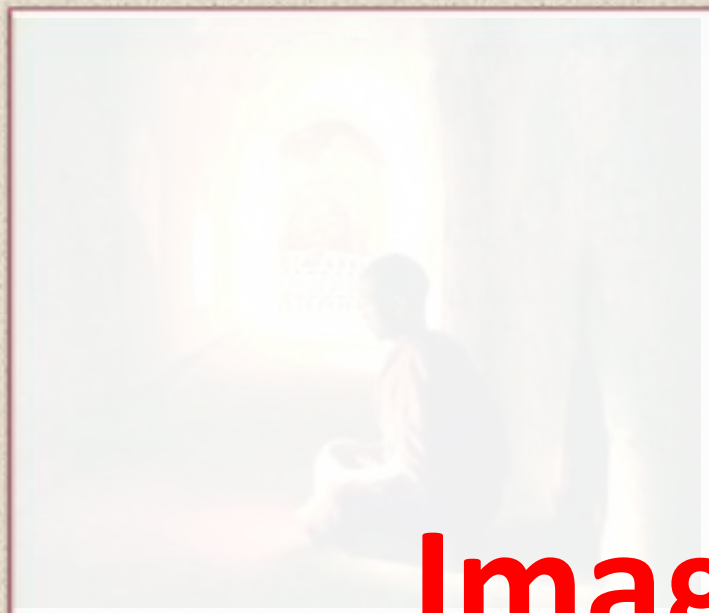


blank screen
(baseline)

mu



Yu Liao, T Mullen, S Makeig, G Deak



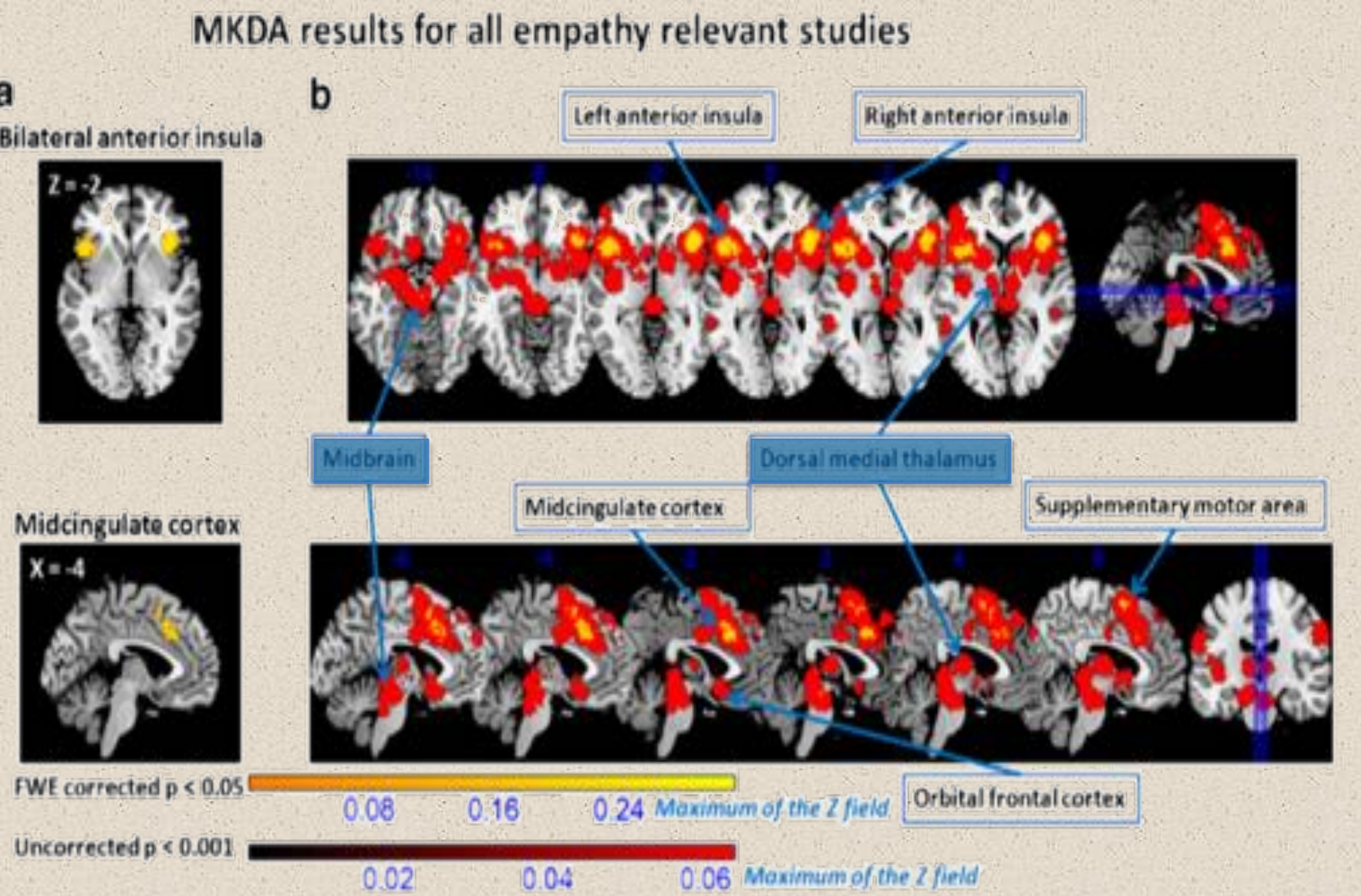
Imaging Empathy

Two Poles of Empathy / Compassion Research

Compassion involves feeling and actively wishing to alleviate another's suffering.

Sympathy is a felt and/or expressed concern for another's suffering.


Empathy

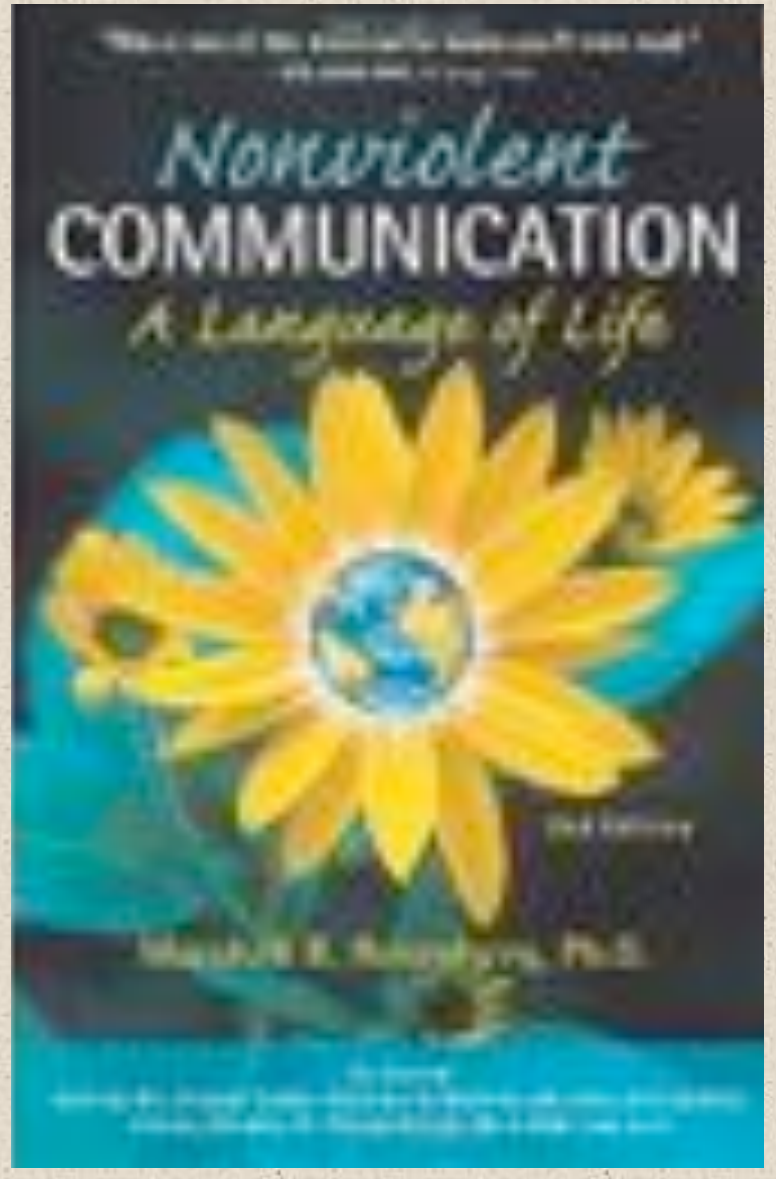


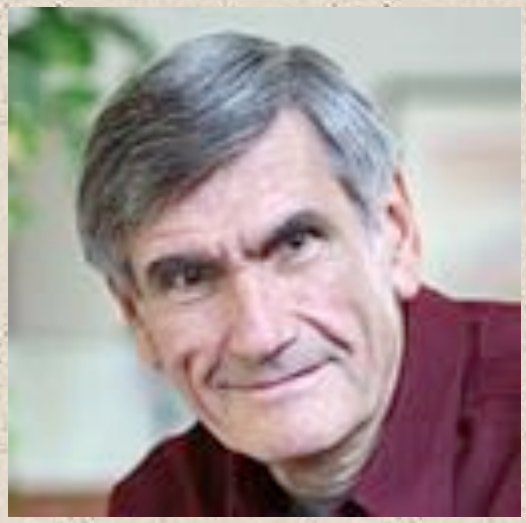
Fan, Y., Duncan, N. W., de Greck, M., Northoff, G. (2011). Is there a core neural network in empathy? An fMRI based quantitative meta-analysis. *Neuroscience & Biobehavioral Reviews* 35(3), 903-911. A meta-analysis of 40 studies.

What form of empathy to study ?

Empathic Listening and Communication

Empathic Communication





Empathic communication through listening

Empathy is a respectful understanding of what others are experiencing. Instead of offering empathy we often have a strong urge to give advice or reassurance and to explain our own position or feeling. Empathy, however, calls upon us to empty our mind and **listen** to others with our whole being.

In ***Nonviolent Communication***, no matter what words others may use to express themselves, we simply listen for their observations, feelings, needs, and requests. Then we may wish to reflect back, paraphrasing what we have understood. We stay with empathy, allowing others the opportunity to fully express themselves before we turn our attention to solutions or requests for relief…

Empathic connection is an understanding of the heart in which we see the beauty in the other person, … the life that's alive in them …

With empathy we don't direct, we follow. **Don't just do something, be there!**

- Marshall Rosenberg *(Nonviolent Communication)*

What is empathy?

"Empathy, I would say is presence. Pure presence to what is alive in a person at this moment, bringing nothing in from the past. The more you know a person, the harder empathy is. The more you have studied psychology, the harder empathy really is. Because you can bring no thinking in from the past… It is about being present … It is not a mental understanding."

Is empathy 'speaking from the heart?'

"In empathy, you don't speak at all. You speak with the eyes. You speak with the body. If you say any words at all, it's because you are not sure you are with the person. So you may say some words. But the words are not empathy. Empathy is when the other person feels the connection to what's alive in you. …

The greatest gift one can give another person is empathy."

- Marshall Rosenberg *(Nonviolent Communication)*

Possible MoBI Experiment Design

'Non-Violent Communication' Training Format

Leader + participant group training sessions

Participant pair practice sessions

MoBI Measures (two-person EEGs + face video + ?)

Video debriefing (each participant separately)

During utterances, contrast *speaker-experienced* and *listener-experienced*

increases vs. decreases in degree of experienced empathic connection

Goals

- Image EEG source dynamics
- Image EEG source network dynamics
- Explore EEG feedback tools, uses in training, etc.

S Makeig, 2012

Psychiatry dept response to this proposed experiment

S Makeig, 2012

Beginning

an electrophysiology of human social interaction

using Mobile Brain/Body Imaging (MoBI)

High-resolution imaging (in time and space)

of cortical dynamics supporting *social cognition.*

sccn.ucsd.edu