

Mining EEG Brain Dynamics: New Directions in Functional Brain Imaging



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Human Functional Brain Imaging

EEG

fMRI

fEEG

MoBI

BCI

ESI

Electromagnetic imaging

= imaging local cortical

Synchrony

3-D imaging more difficult,
but quite fast & direct.

Hemodynamic imaging

= imaging brain

Energy

Direct 3-D imaging,
but quite slow & indirect

Human EEG History

Some EEG milestones

1926 ~1st human functional brain 'imaging'

1938 1st EEG spectral analysis

'reading the EEG'

1962 1st computer for EP averaging (CAT)

'event-related potential (ERP) averaging'

1995 1st multisource EEG filtering by ICA

'functional EEG brain imaging'

2009 ~1st commercial dry electrode devices

'mobile, wireless, wearable MoBI'

201? ~1st extremely high density ECoG system

'electrocortical source imaging (ESI)'

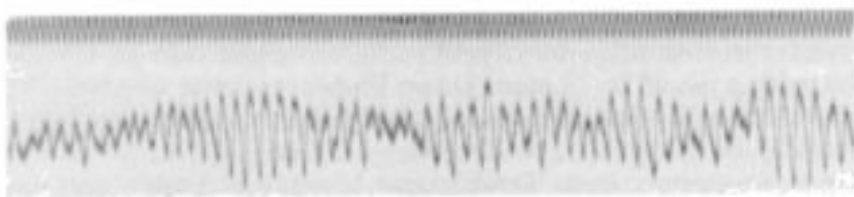
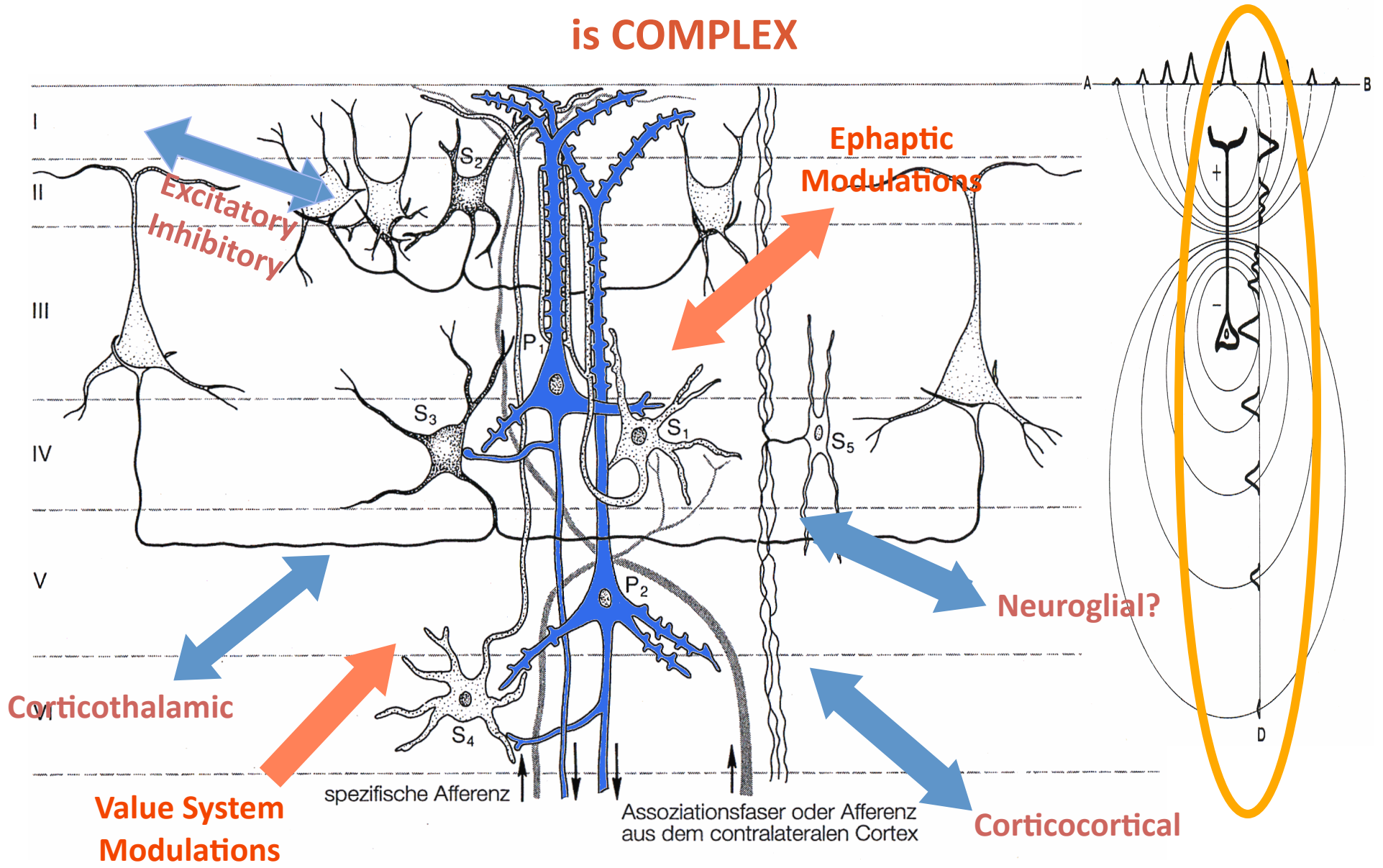


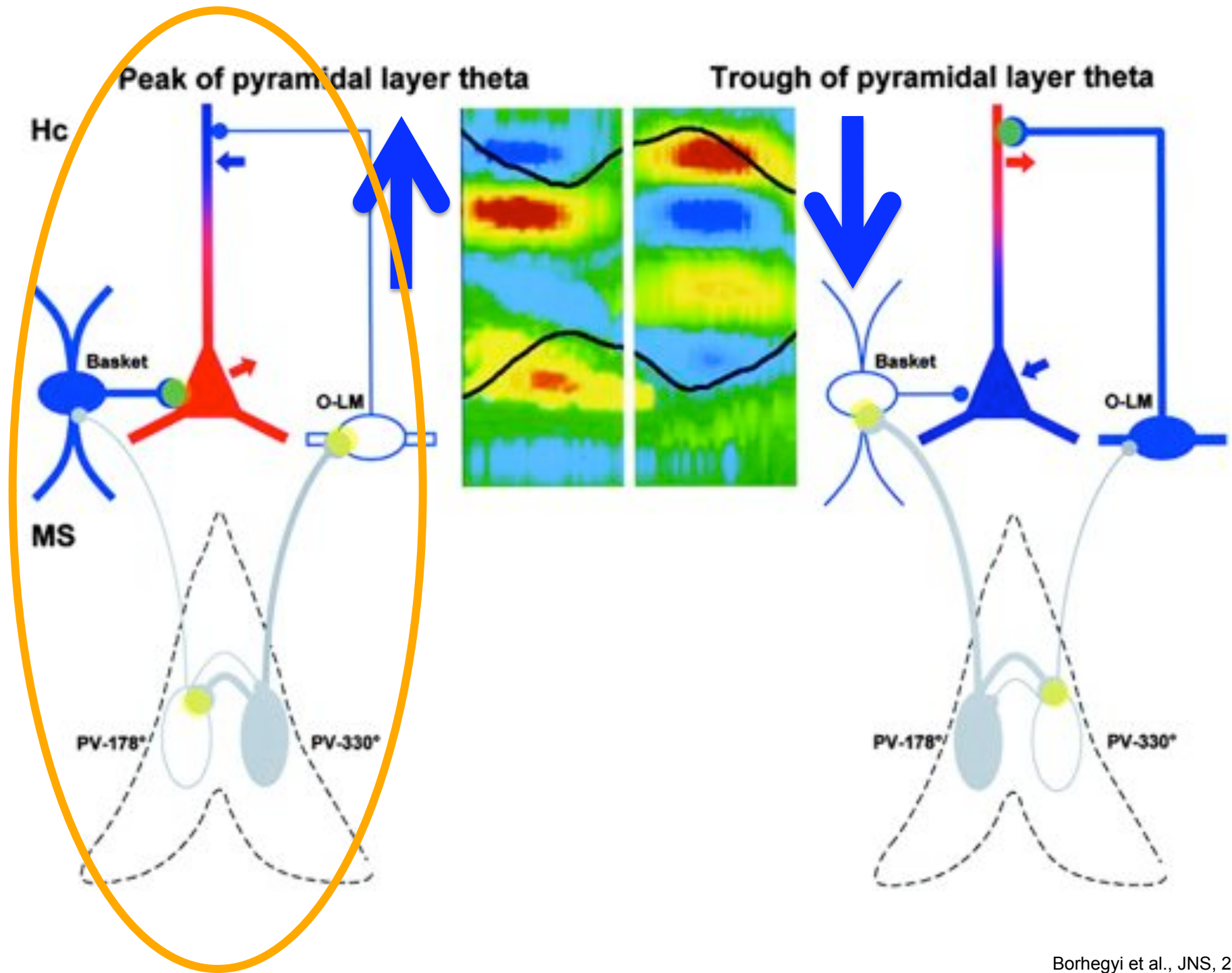
FIGURE 1-2.—Sample of the first EEG tracing taken at the Bradley Hospital, E. Providence, Rhode Island, by H. Jasper and L. Carmichael. Subject: Carl Pfaffmann. Date: July 9, 1934. Record, which shows prominent alpha rhythm of about 11.5 per second, was made with a Westinghouse, galvanometer-type, mirror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



FIGURE 1-1.—Professor Hans Berger (1873-1941), neuro-psychiatrist, 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).

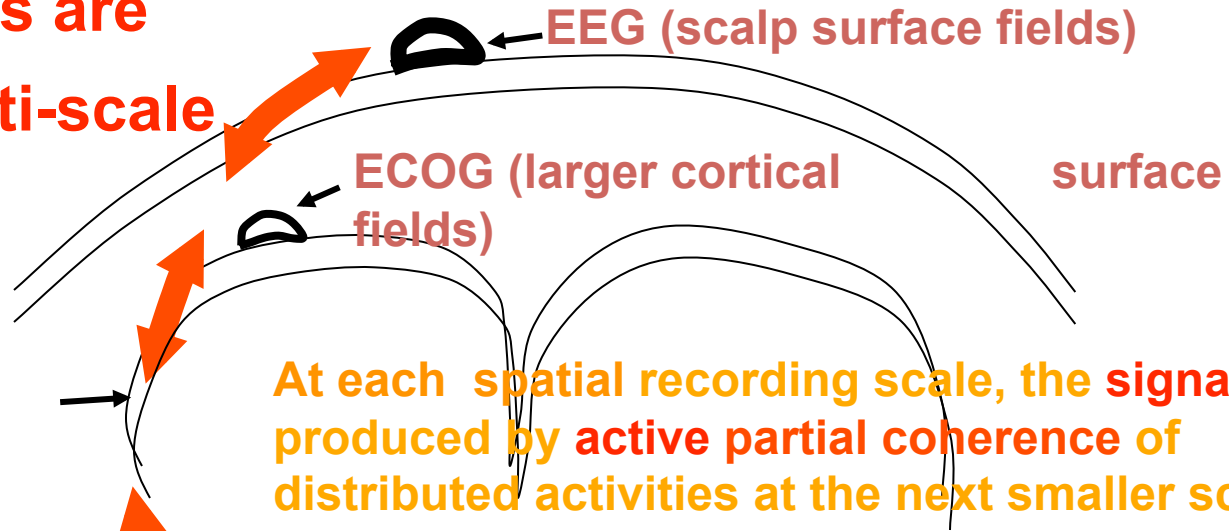
The generation and modulation of EEG / LFP is COMPLEX





**Brain dynamics are
inherently multi-scale**

Local
Extracellular
Fields



Intracellular and peri-cellular fields

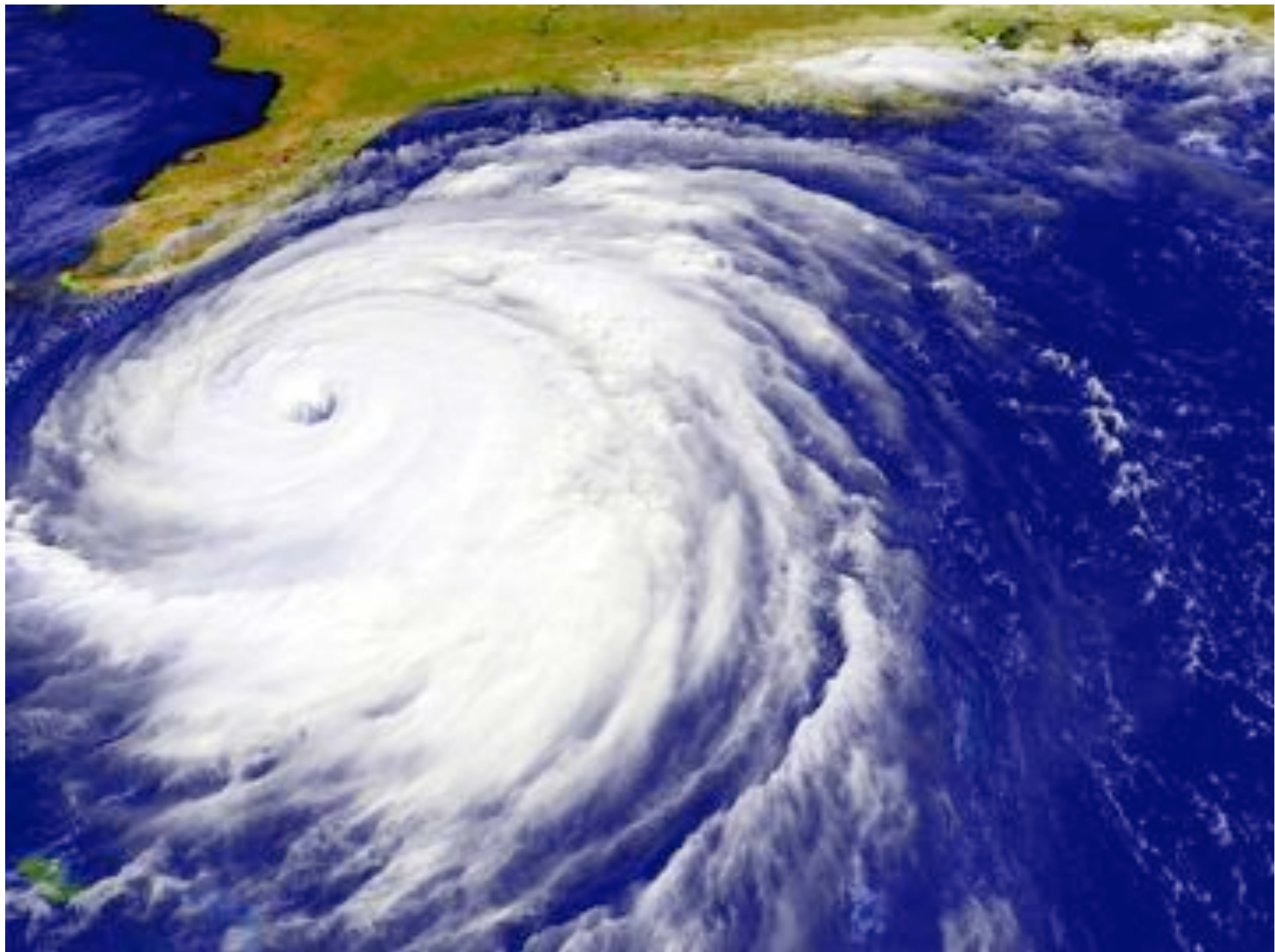
Synaptic and other trans-membrane potentials

Scale chauvinism

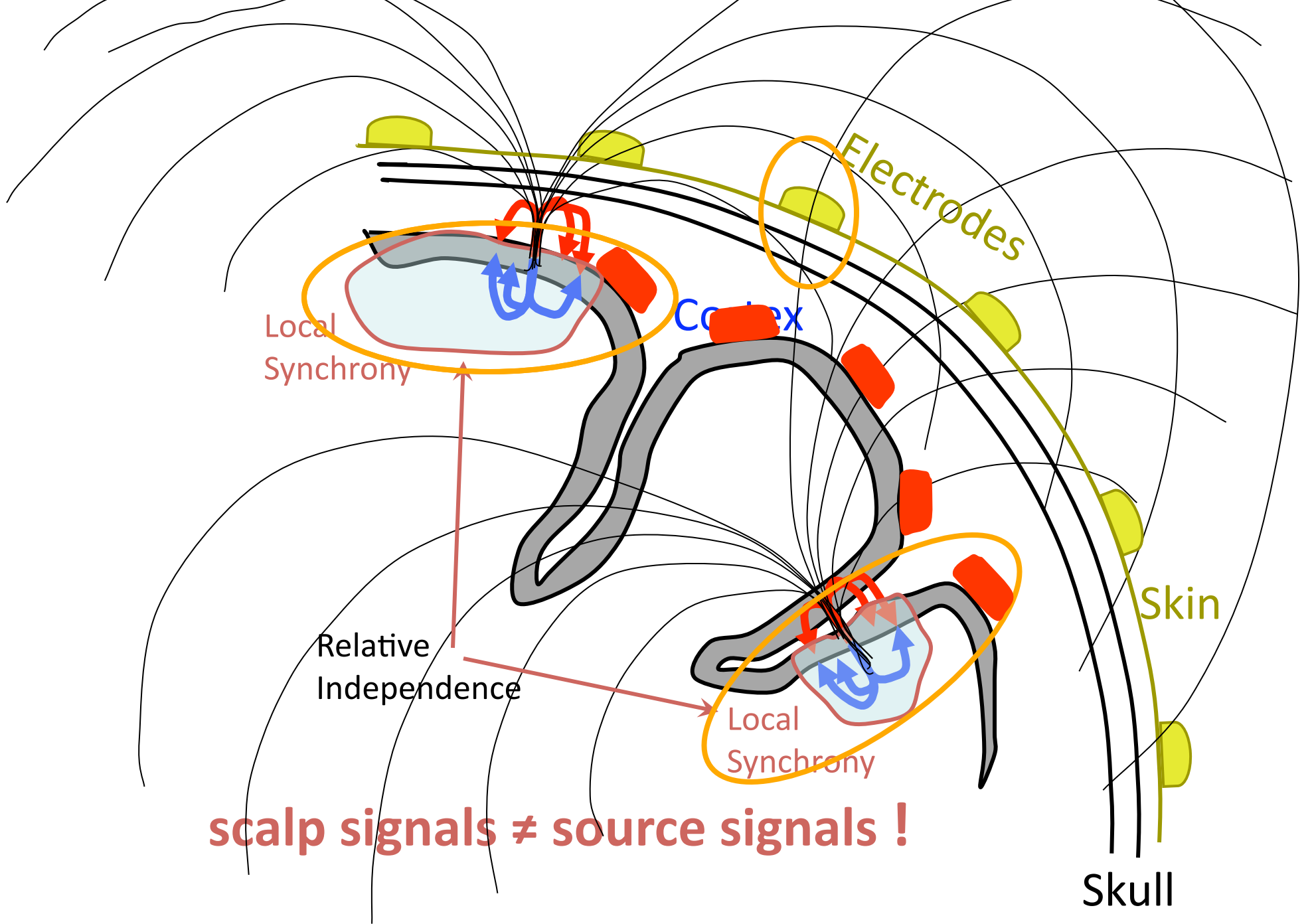
Phase cones (Freeman)

Avalanches (Plenz)

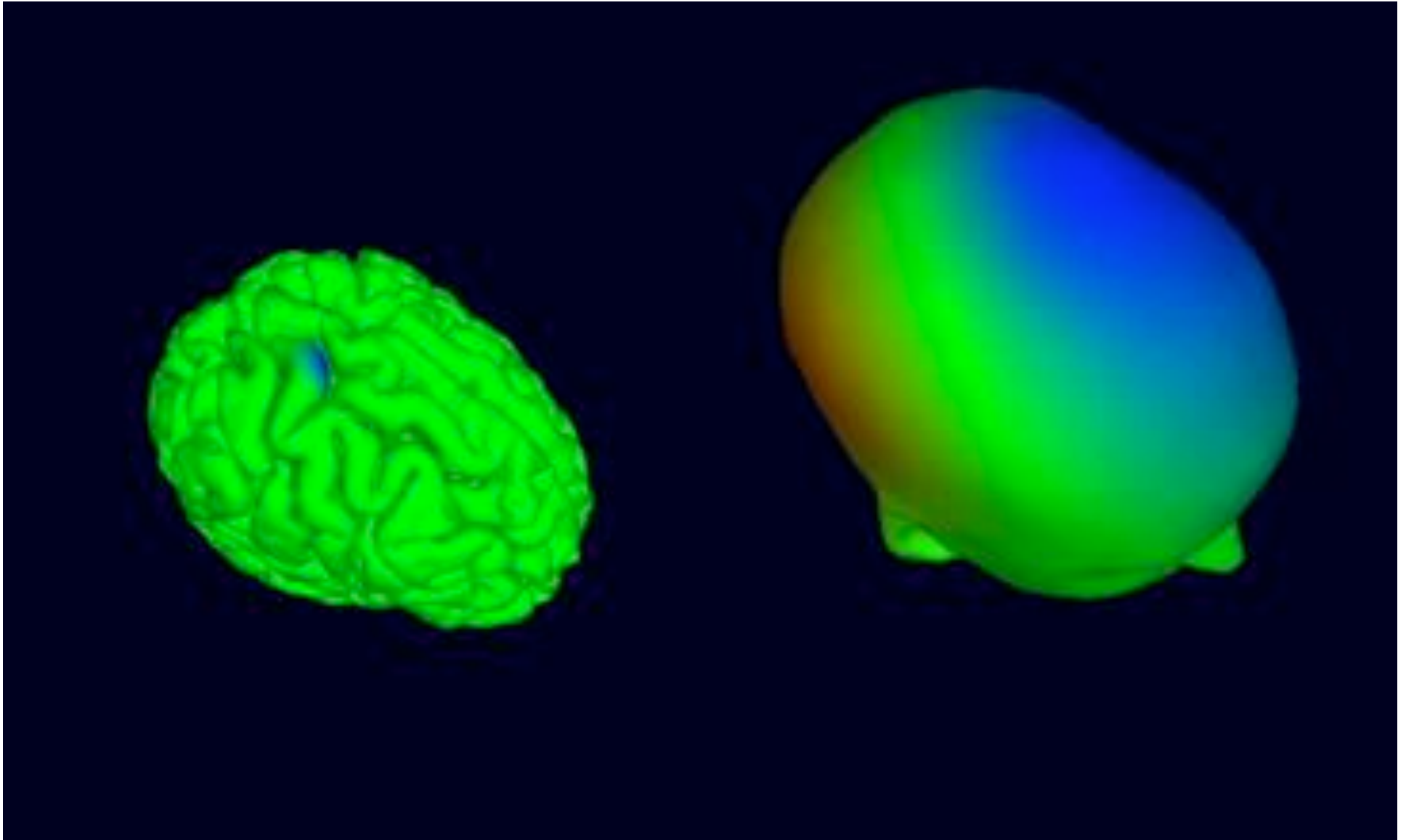




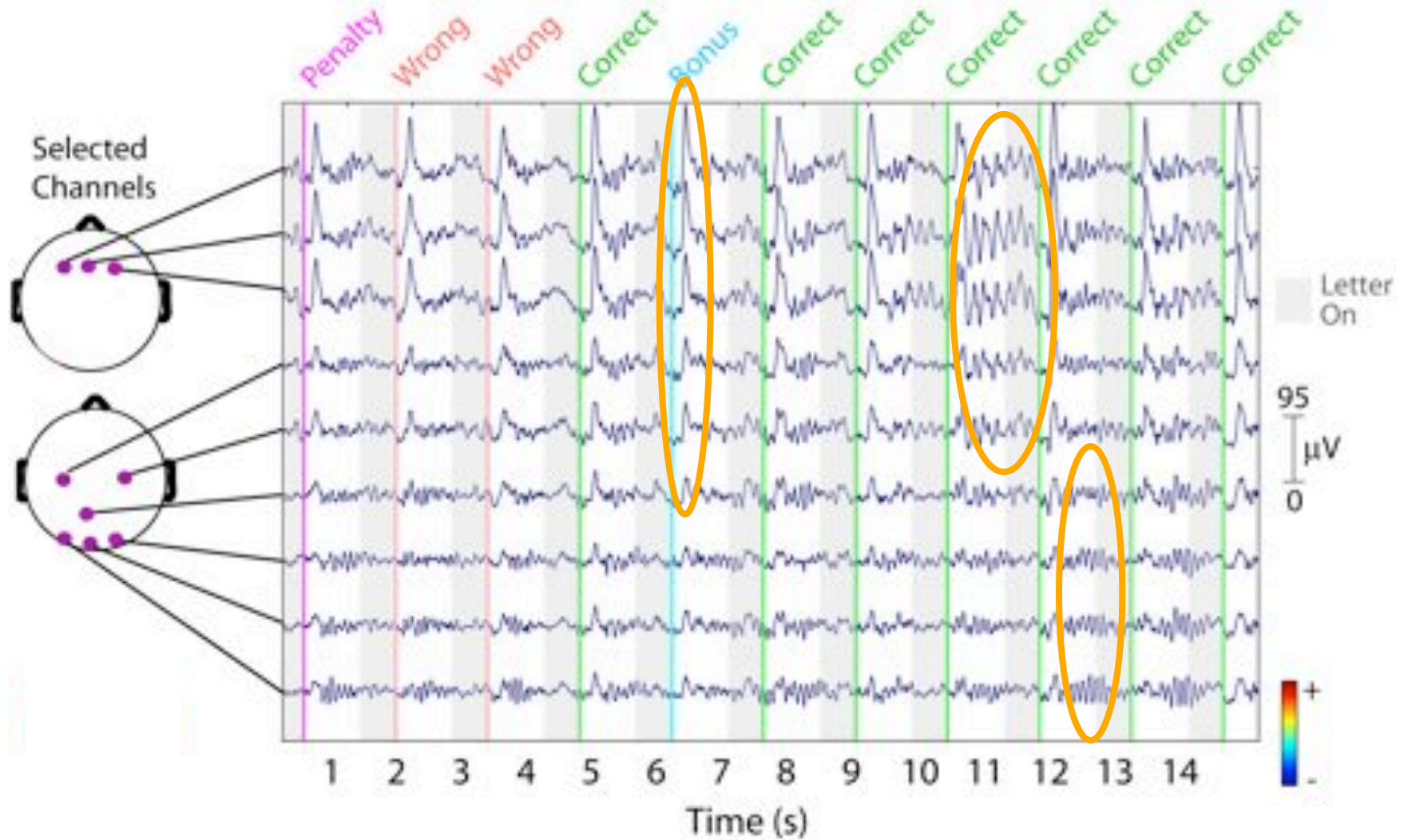




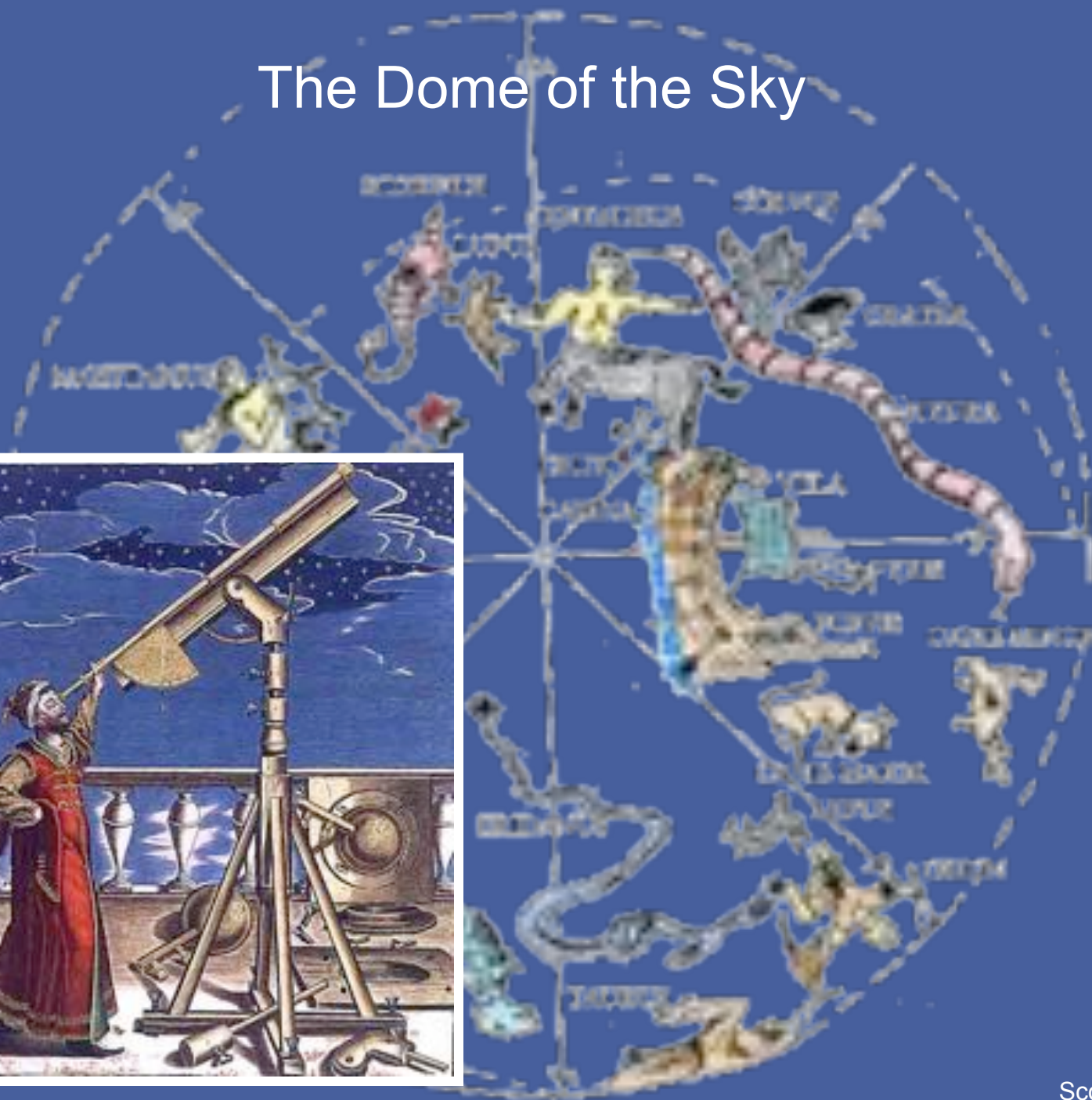
The very broad EEG point-spread function



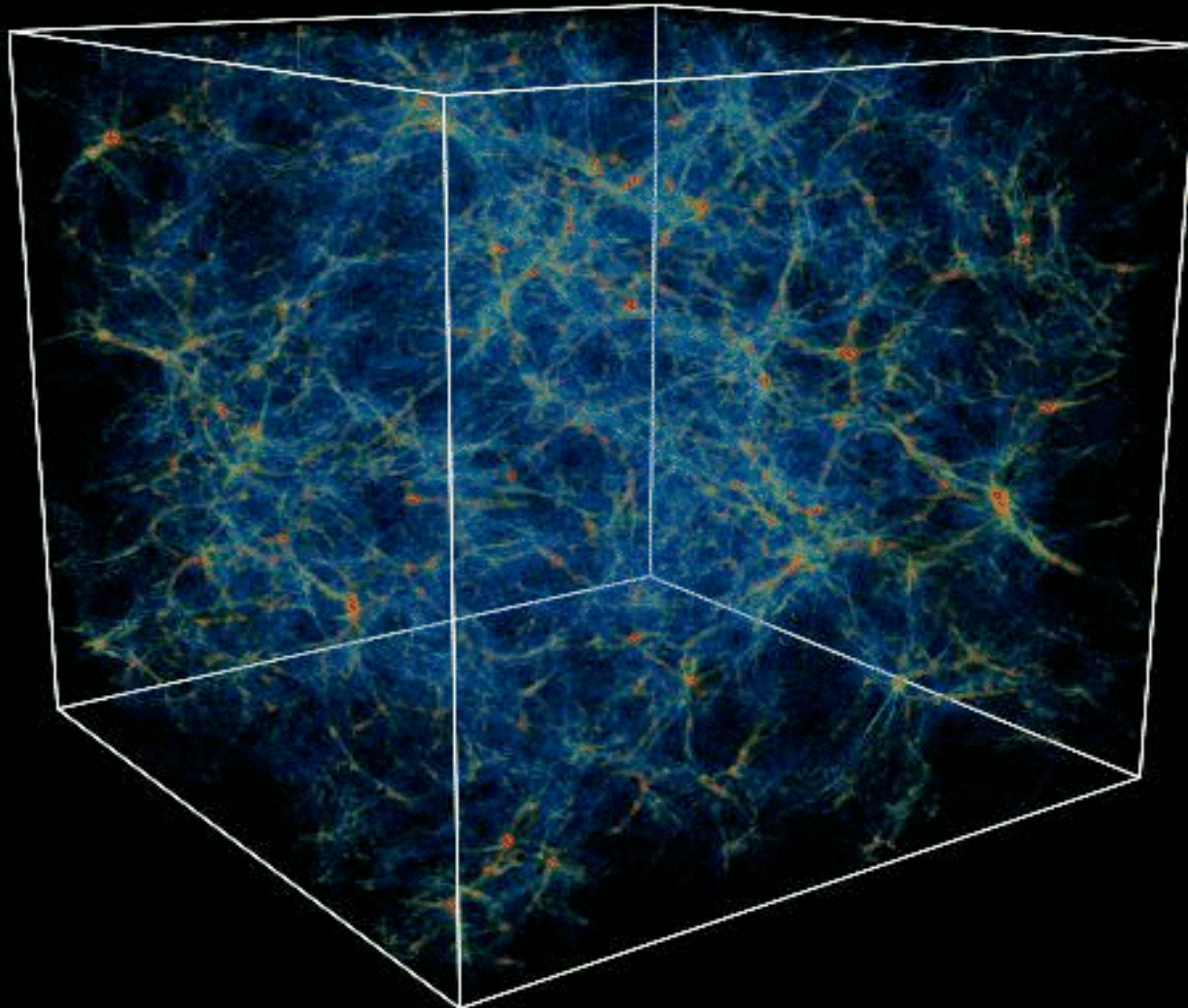
Human Electroencephalogram (EEG)

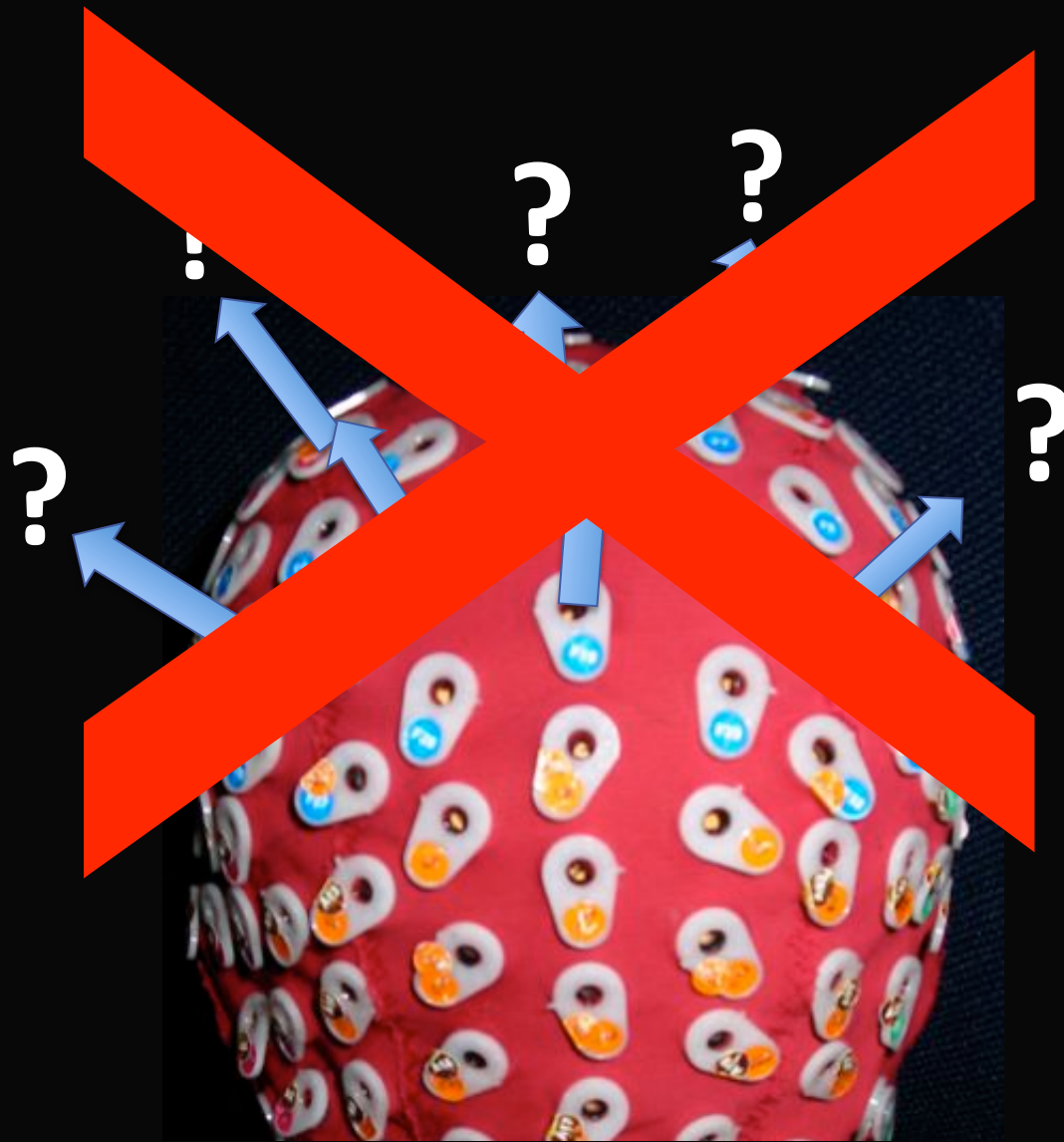


The Dome of the Sky



3-D structure of the Universe

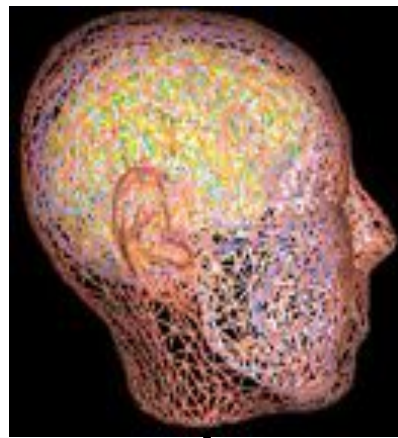




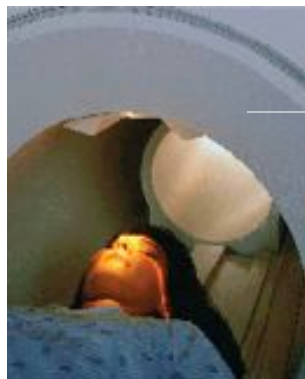
2-D Interpretation of Scalp EEG Signals ?

Electromagnetic source localization

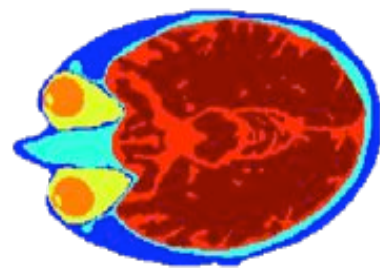
Solve the forward problem using realistic head models (BEM)



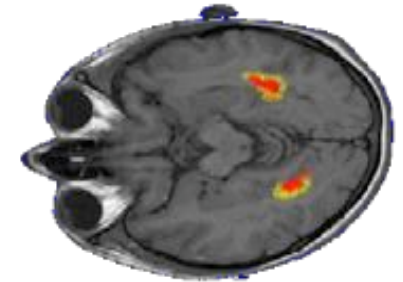
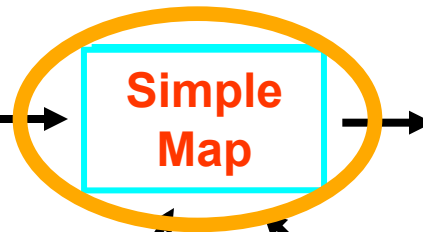
Mesh generation



MRI



Segmentation



Source Image

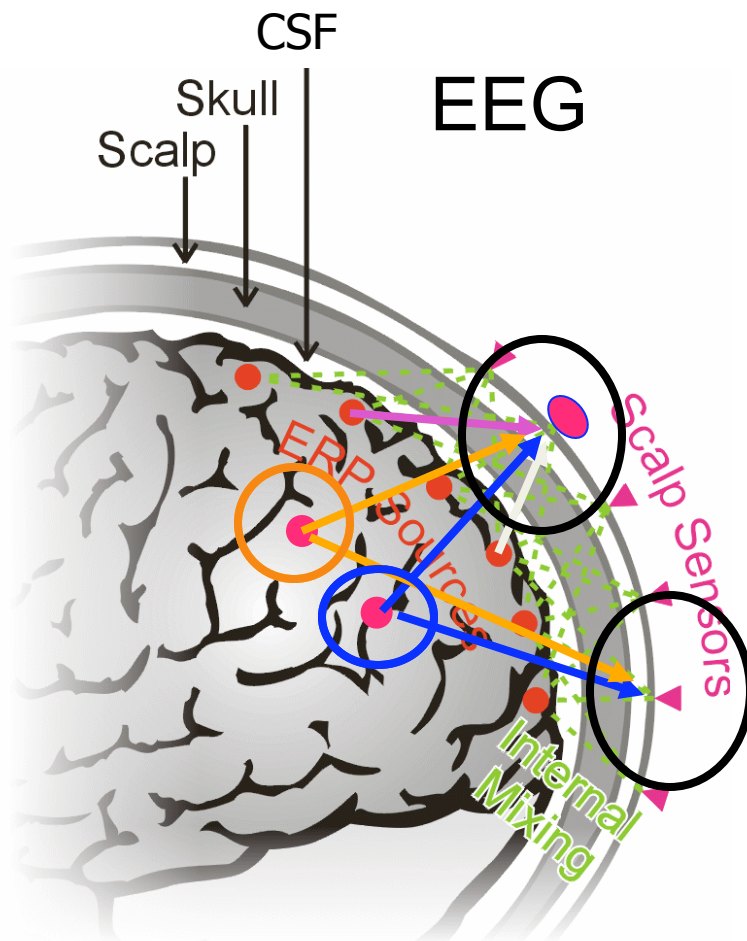
Sensor Localization

Signal Processing

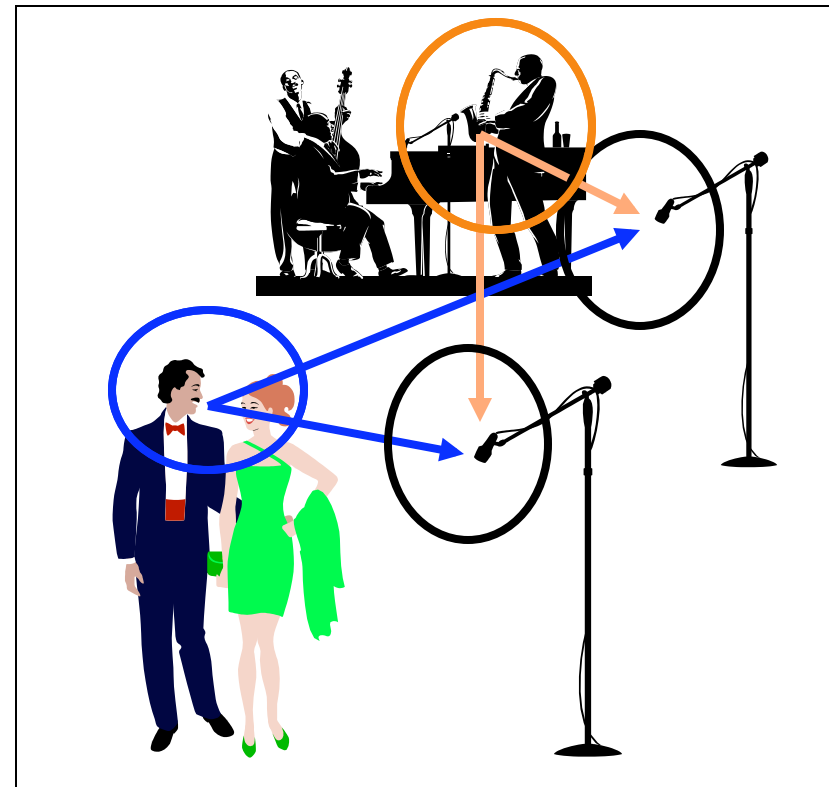


EEG/MEG

Blind EEG Source Separation by Independent Component Analysis



Cocktail Party



Independent Component Analysis of Electroencephalographic Data



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Abstract

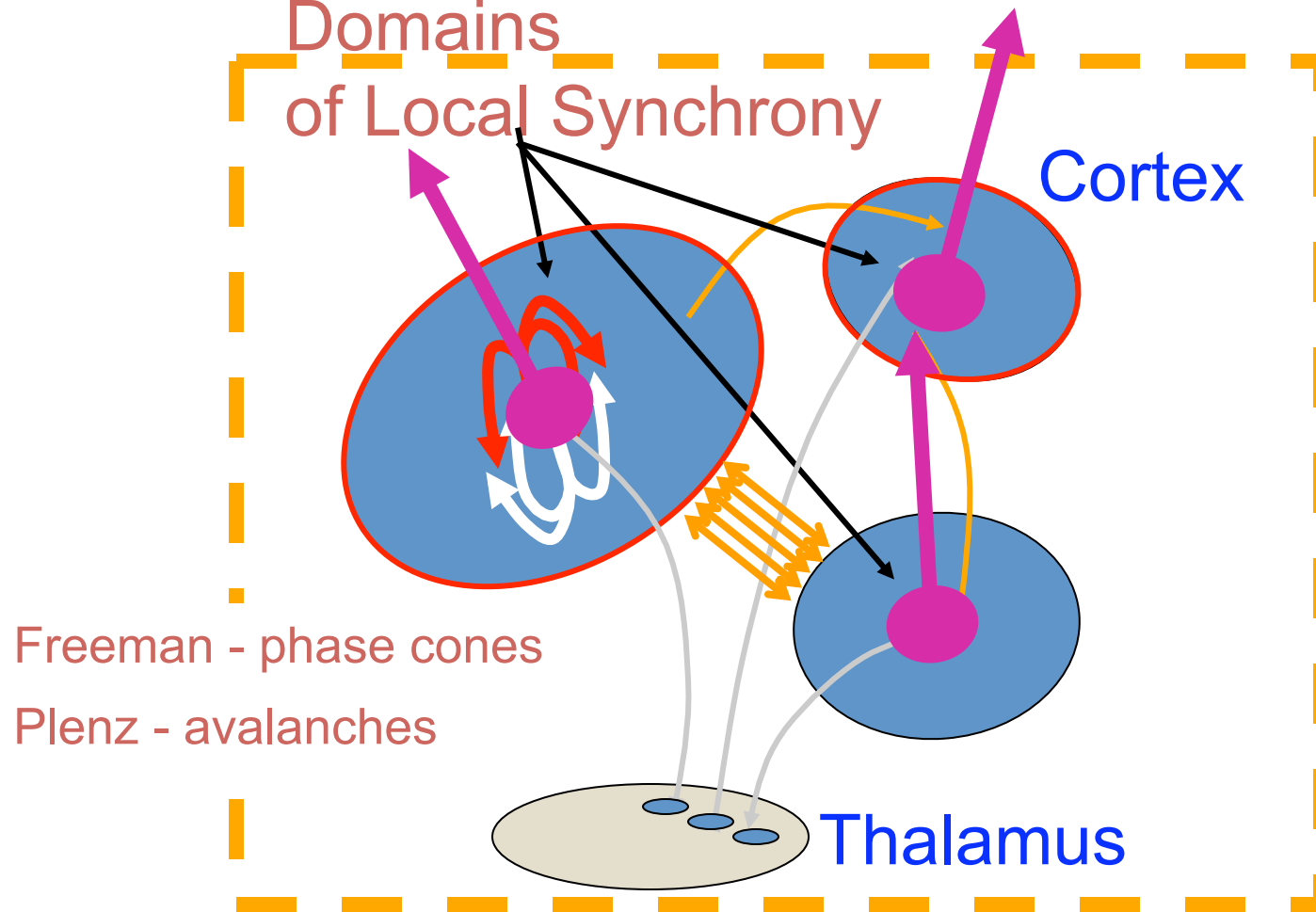
Presence of the division between the skull and brain and their different conductivities, electroencephalographic (EEG) data collected from any point on the human scalp includes activity generated within a large brain area. The spatial smearing of EEG data by volume conduction does not hinder significant time delays, however, and

Infomax ICA

of applying the ICA algorithm to extract anatomical sources (IAS) data collected during a sustained auditory detection task show: (1) ICA tracking is insensitive to different random seeds, (2) ICA may be used to separate obvious collected EEG components (eye movements, eye movements, slow waves), (3) ICA is capable of isolating overlapping EEG phenomena, including alpha and theta bands and spatially separate EEG components, to separate ICA channels, (4) Nonstationarities in EEG and behavioral state can be tracked using ICA via changes in the amount of mutual correlation between ICA filtered output channels.

Are EEG source outputs (nearly) independent?

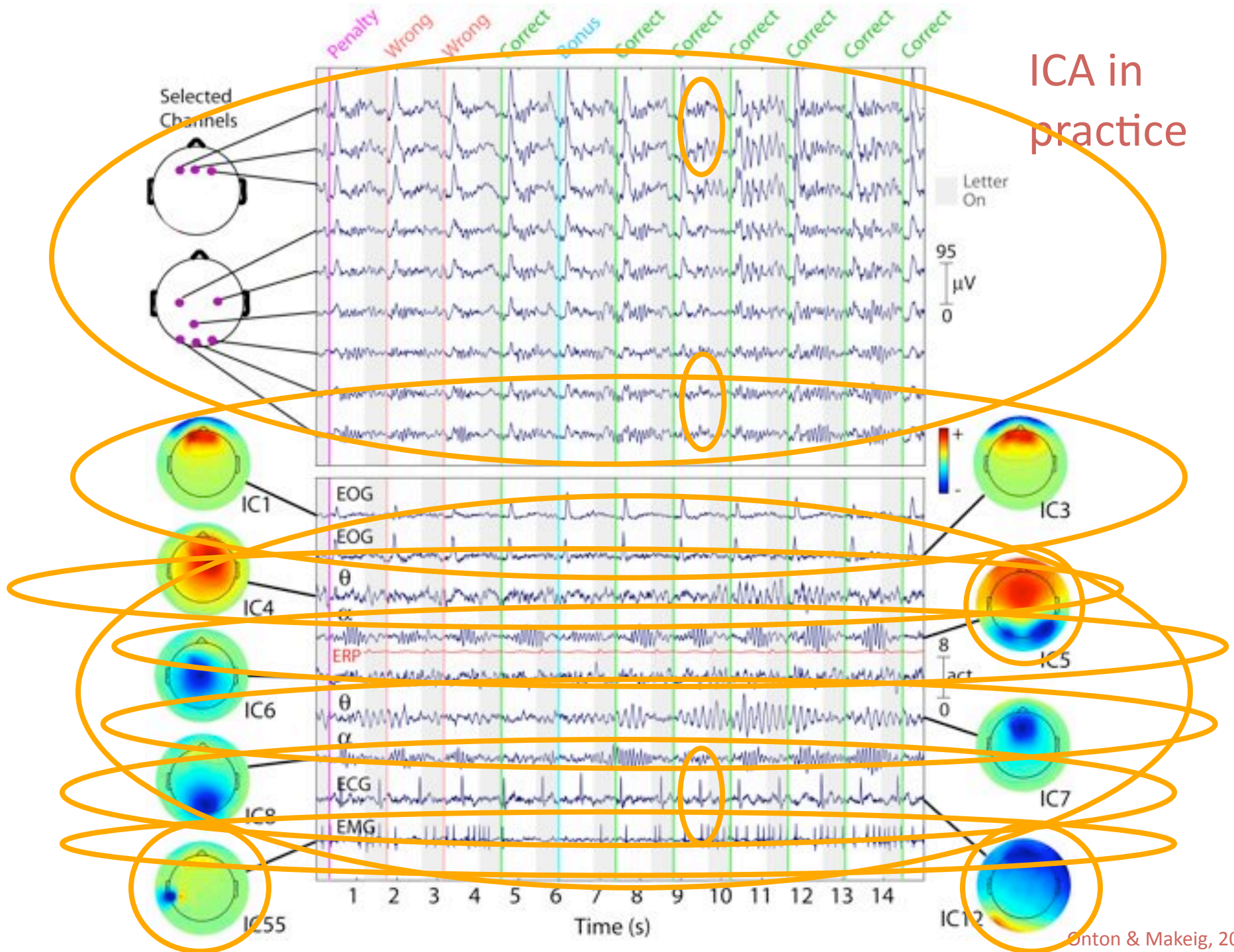
**Independent
Domains
of Local Synchrony**



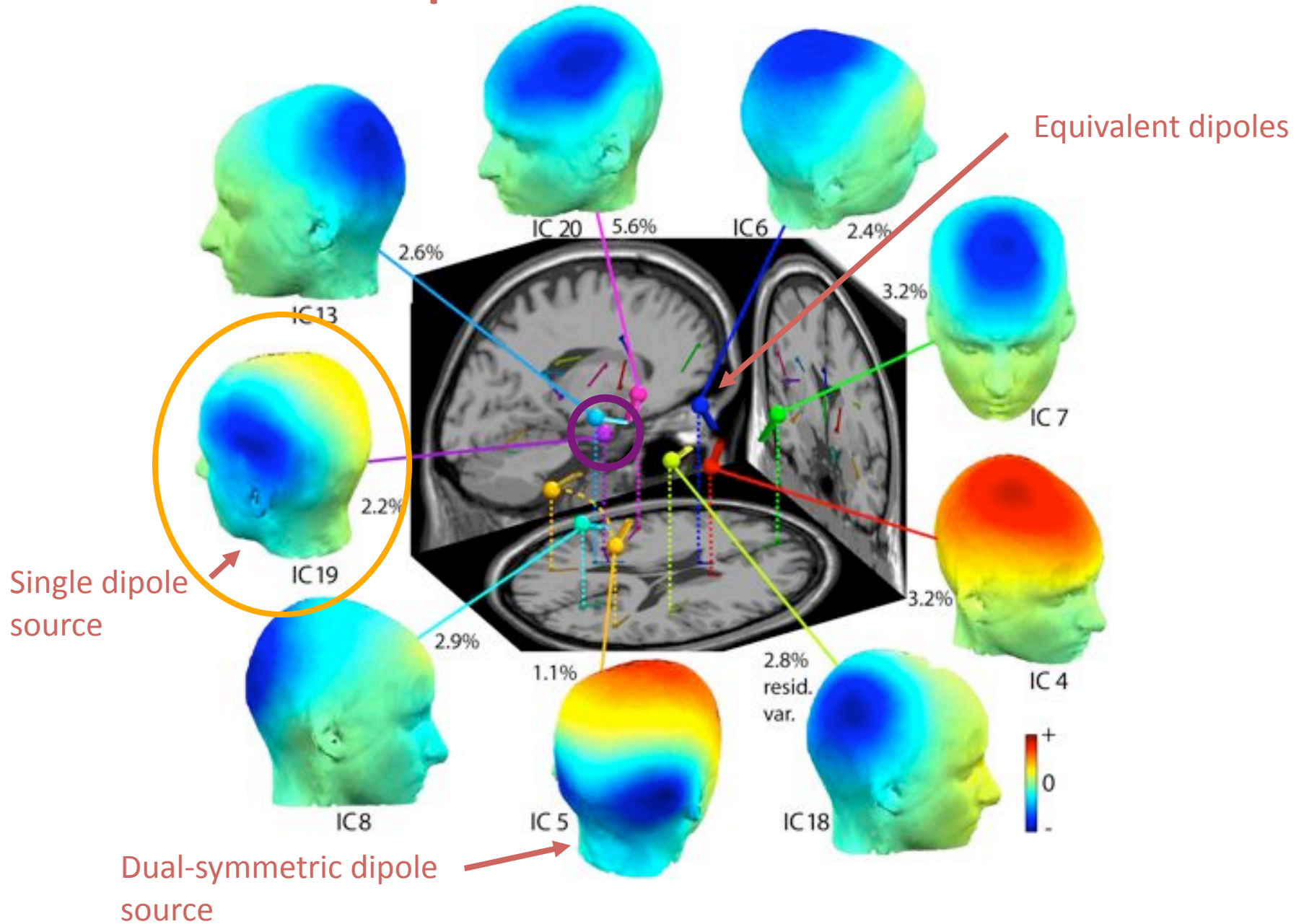
Freeman - phase cones

Plenz - avalanches

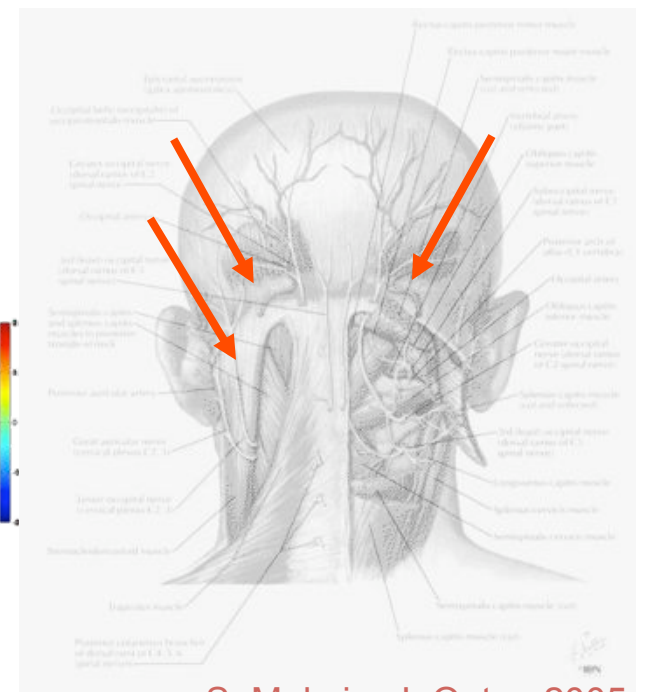
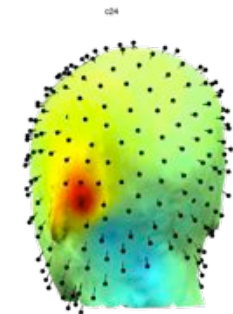
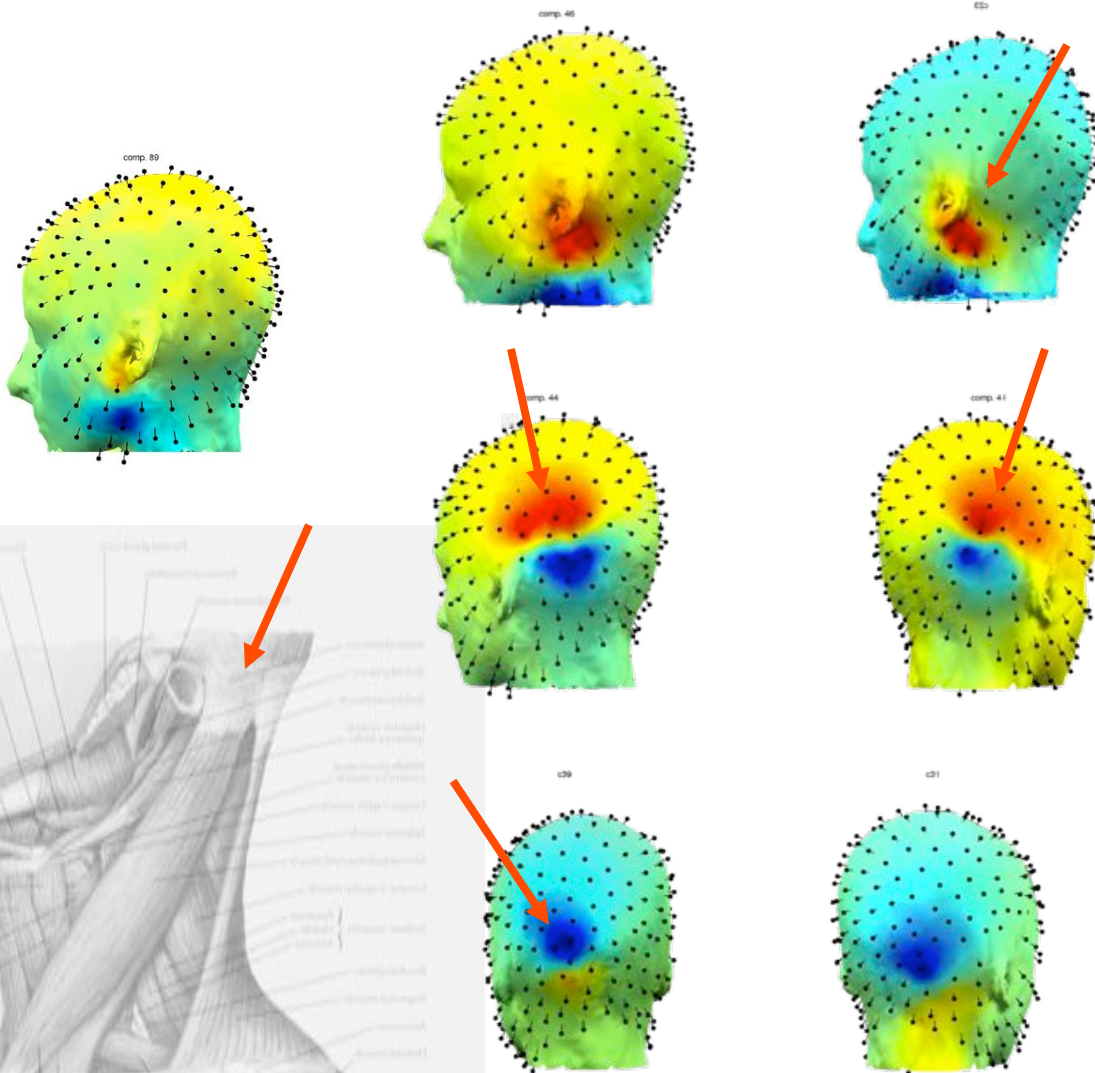
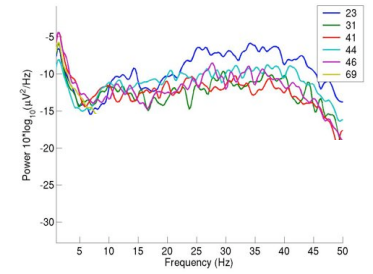
ICA in practice



Compact cortical EEG sources



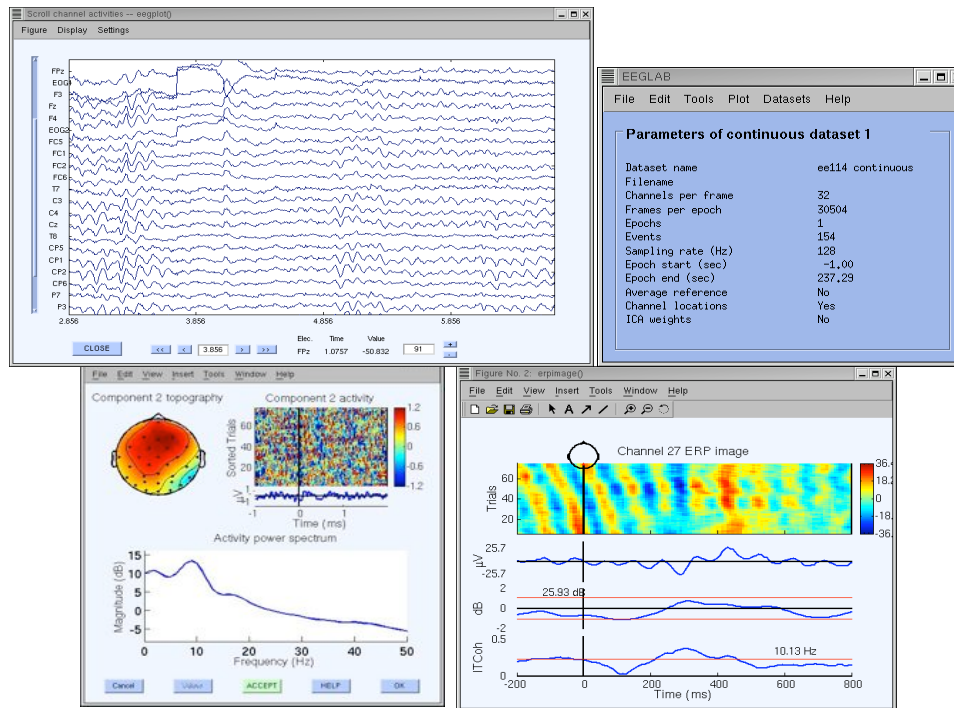
Independent muscle signals



S. Makeig, J. Onton 2005

EEGLAB

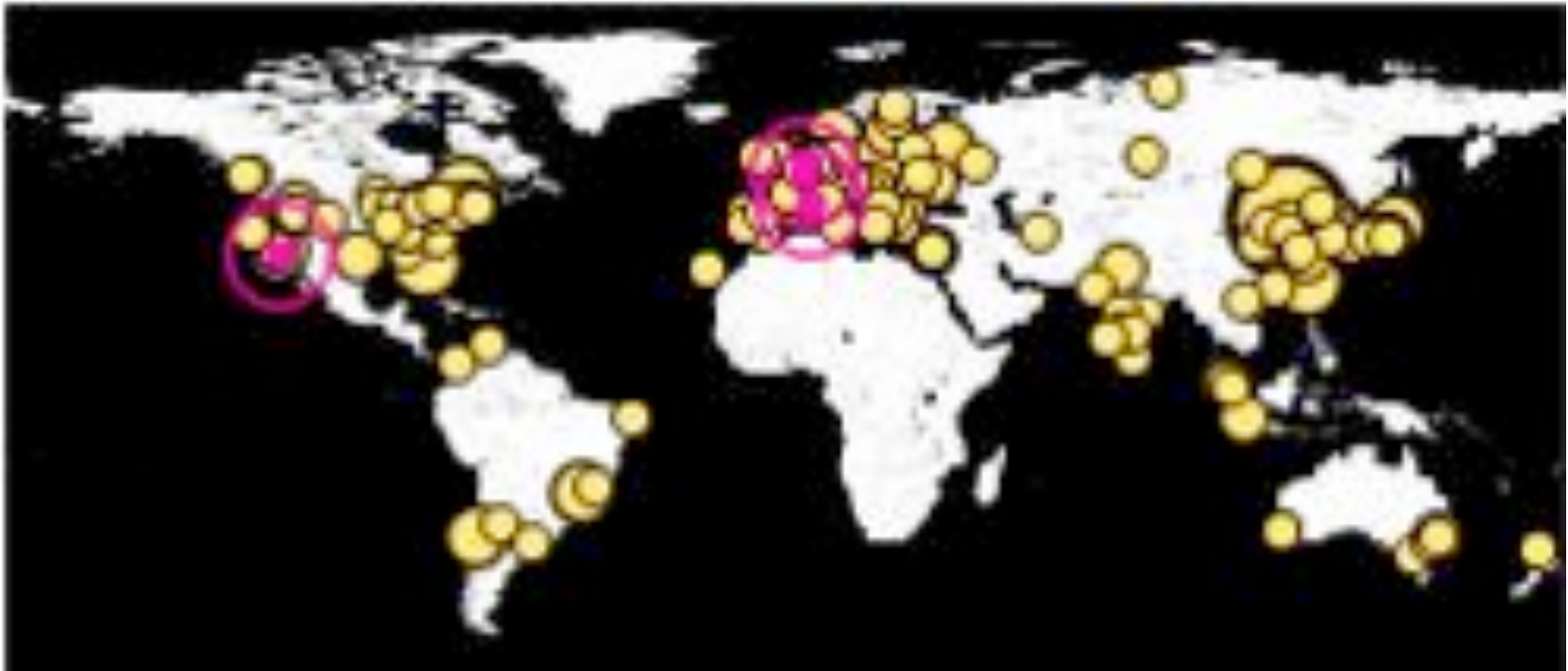
An open-source signal processing environment for Matlab



<http://sccn.ucsd.edu/eeglab>

EEGLAB

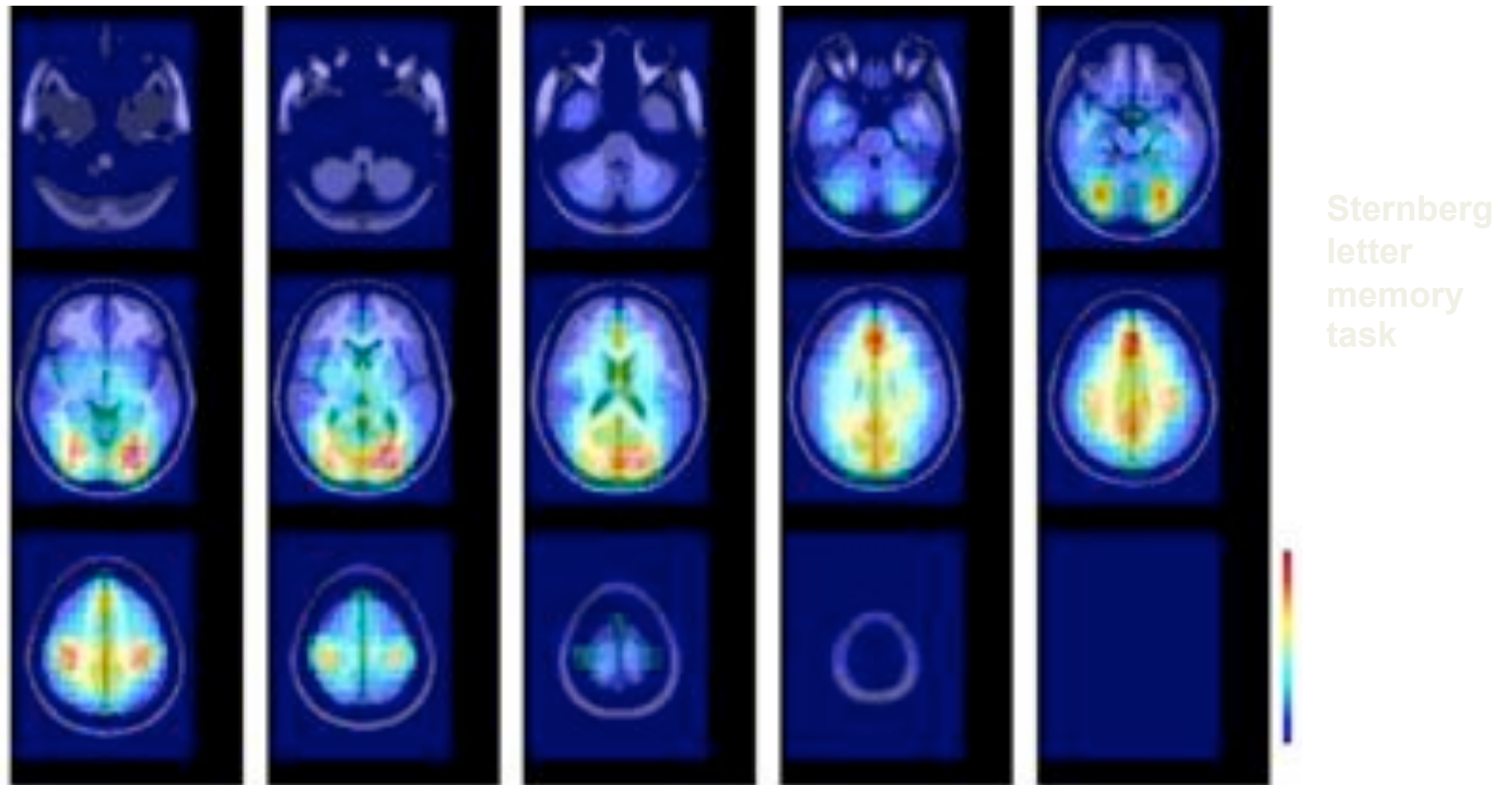
An open-source signal processing
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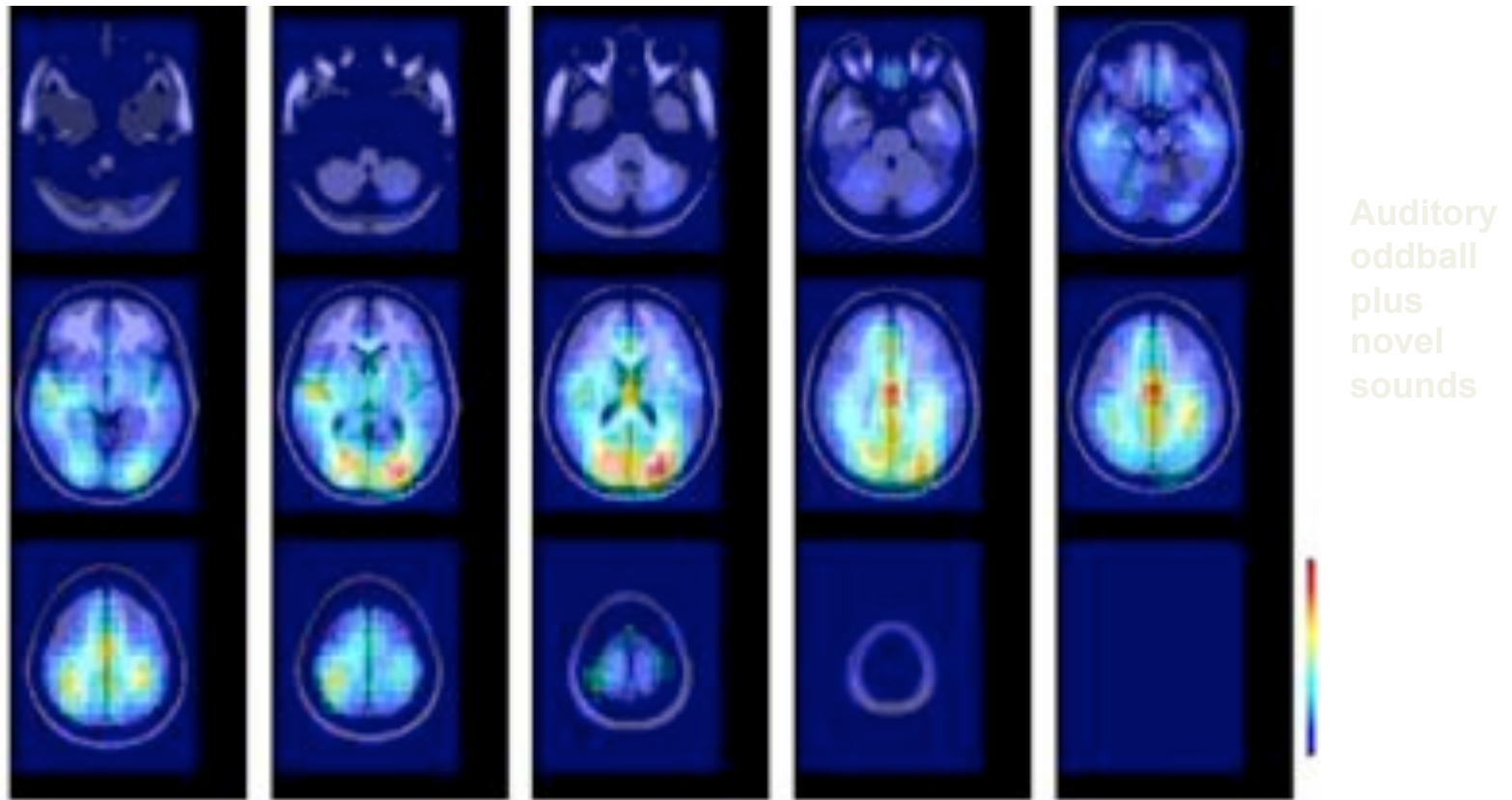
Equivalent dipole density

Visual Working Memory



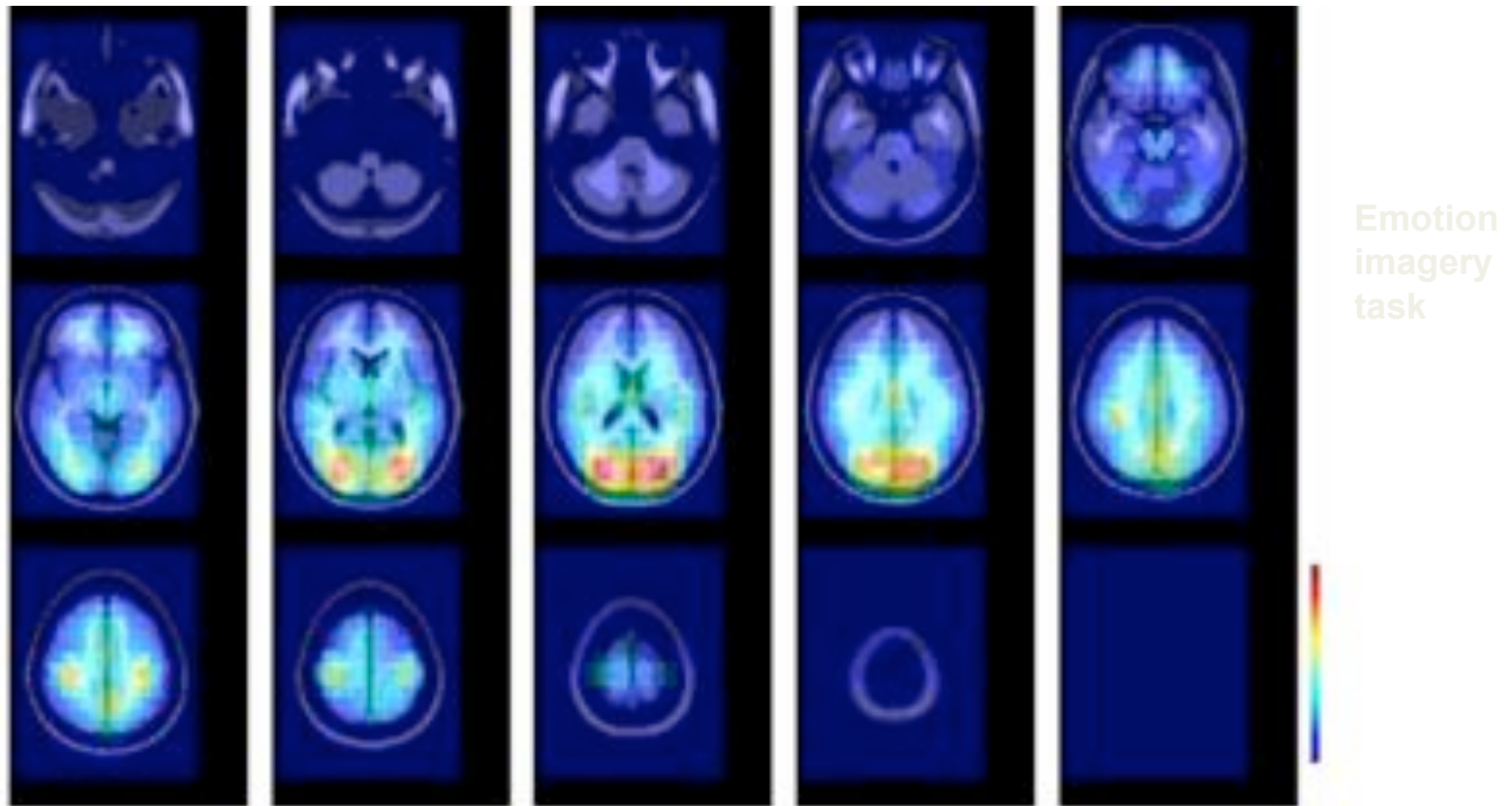
Equivalent dipole density

Auditory Novelty



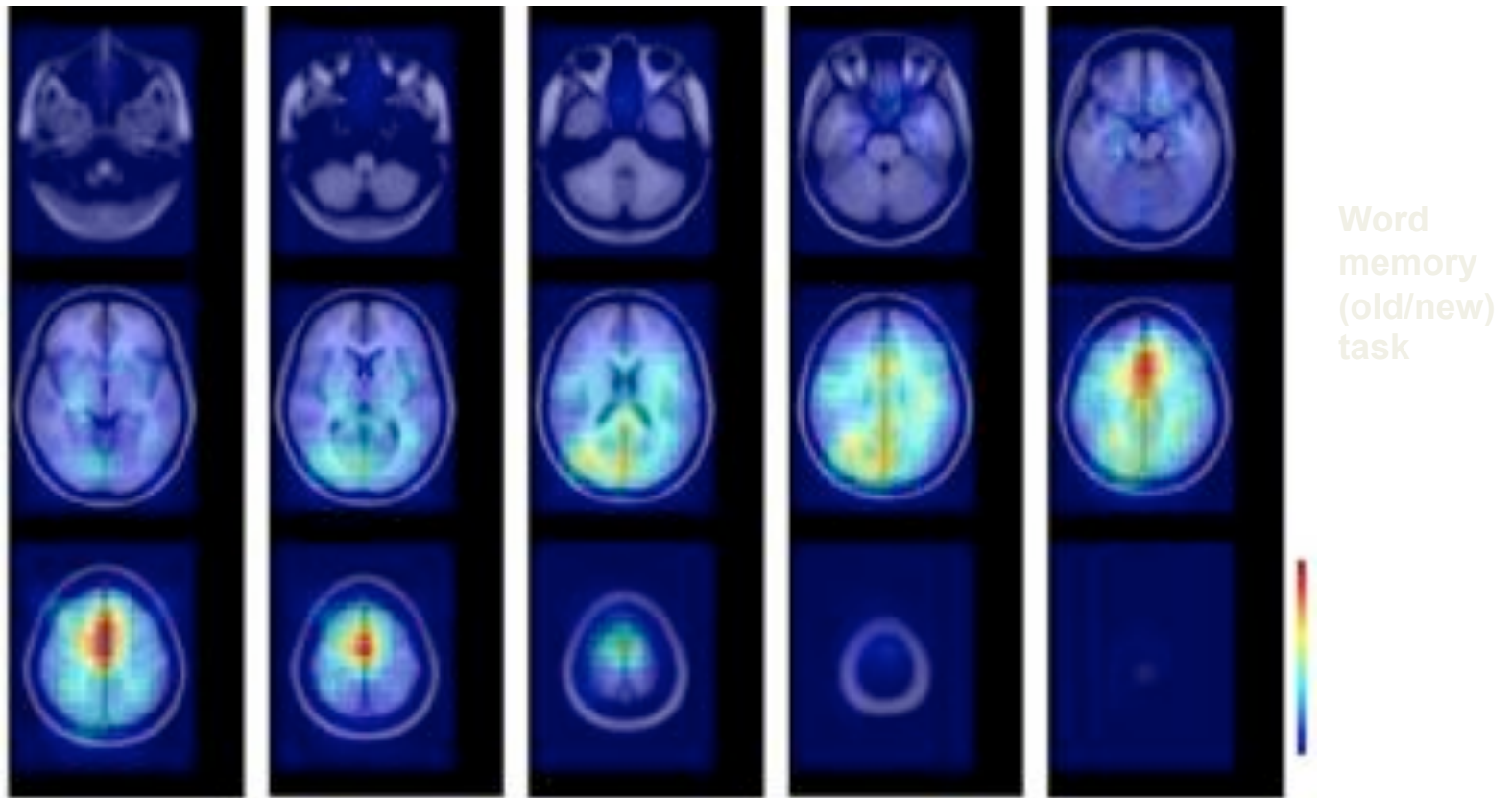
Equivalent dipole density

Emotion Imagination



Equivalent dipole density

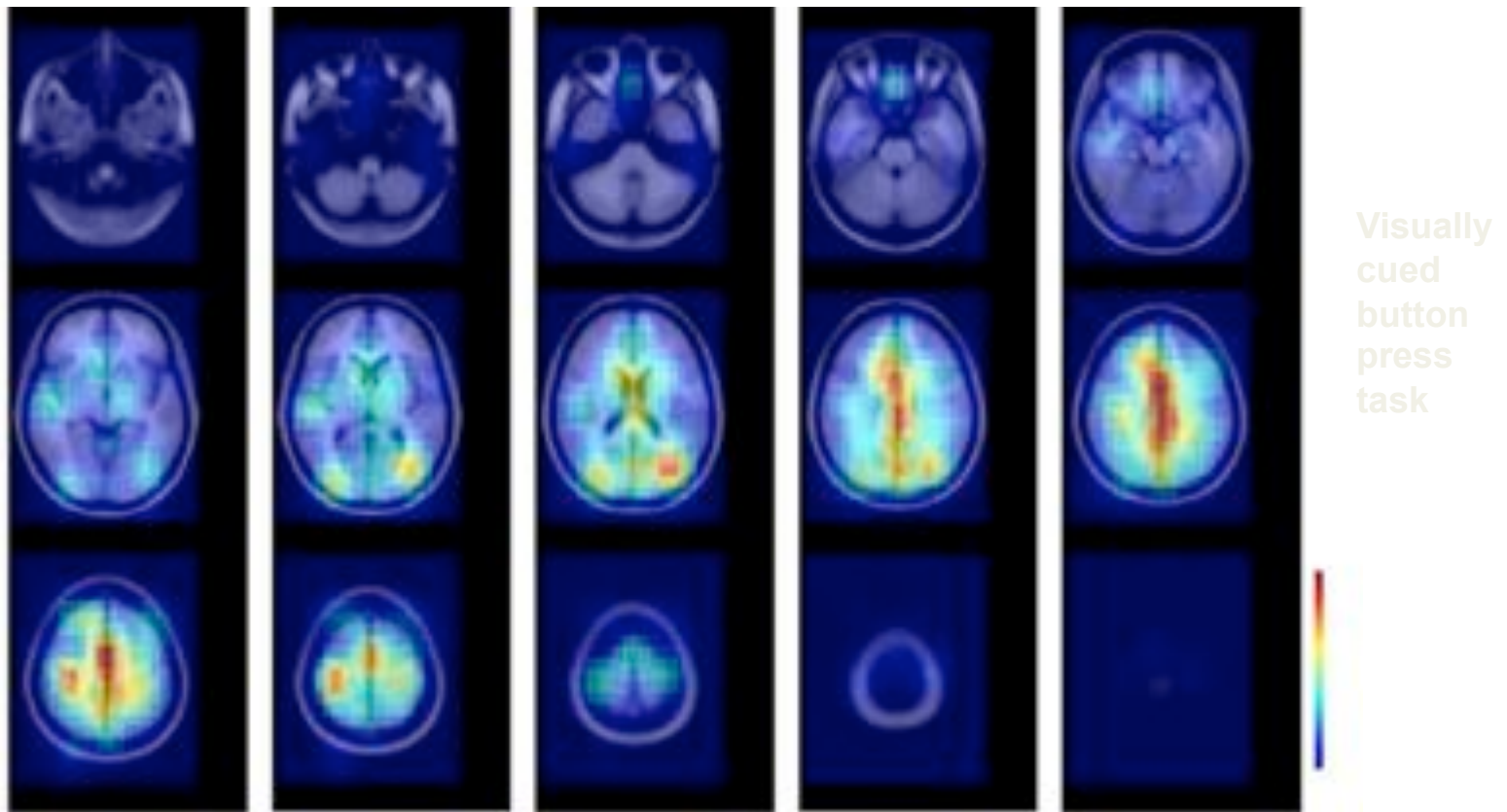
Task A – Old/New Word Memory



dipoledensity()

Equivalent dipole density

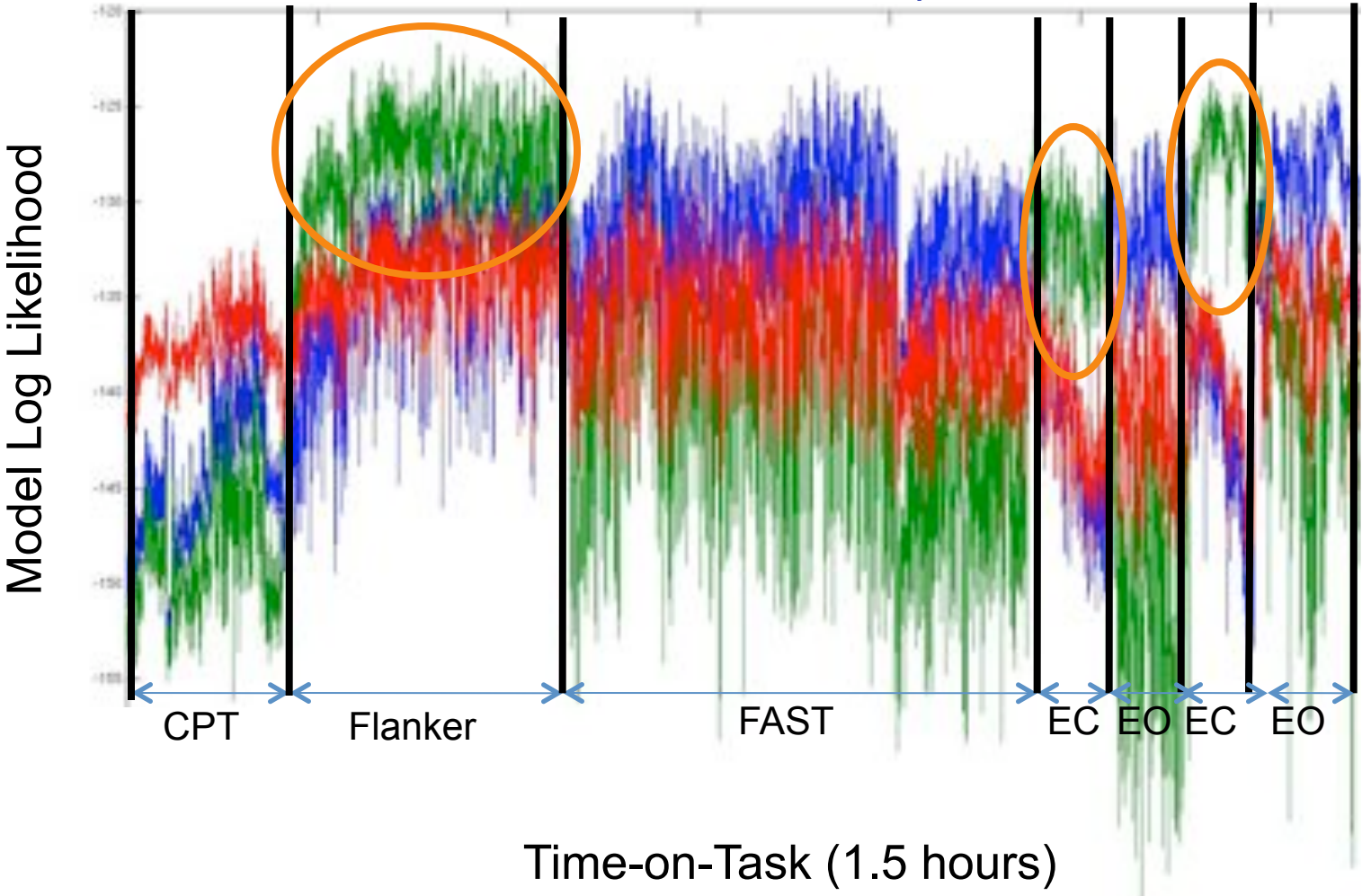
Task B – Cued finger movements



dipoledensity()

Modeling Spatiotemporal Variability

3-Model AMICA Decomposition



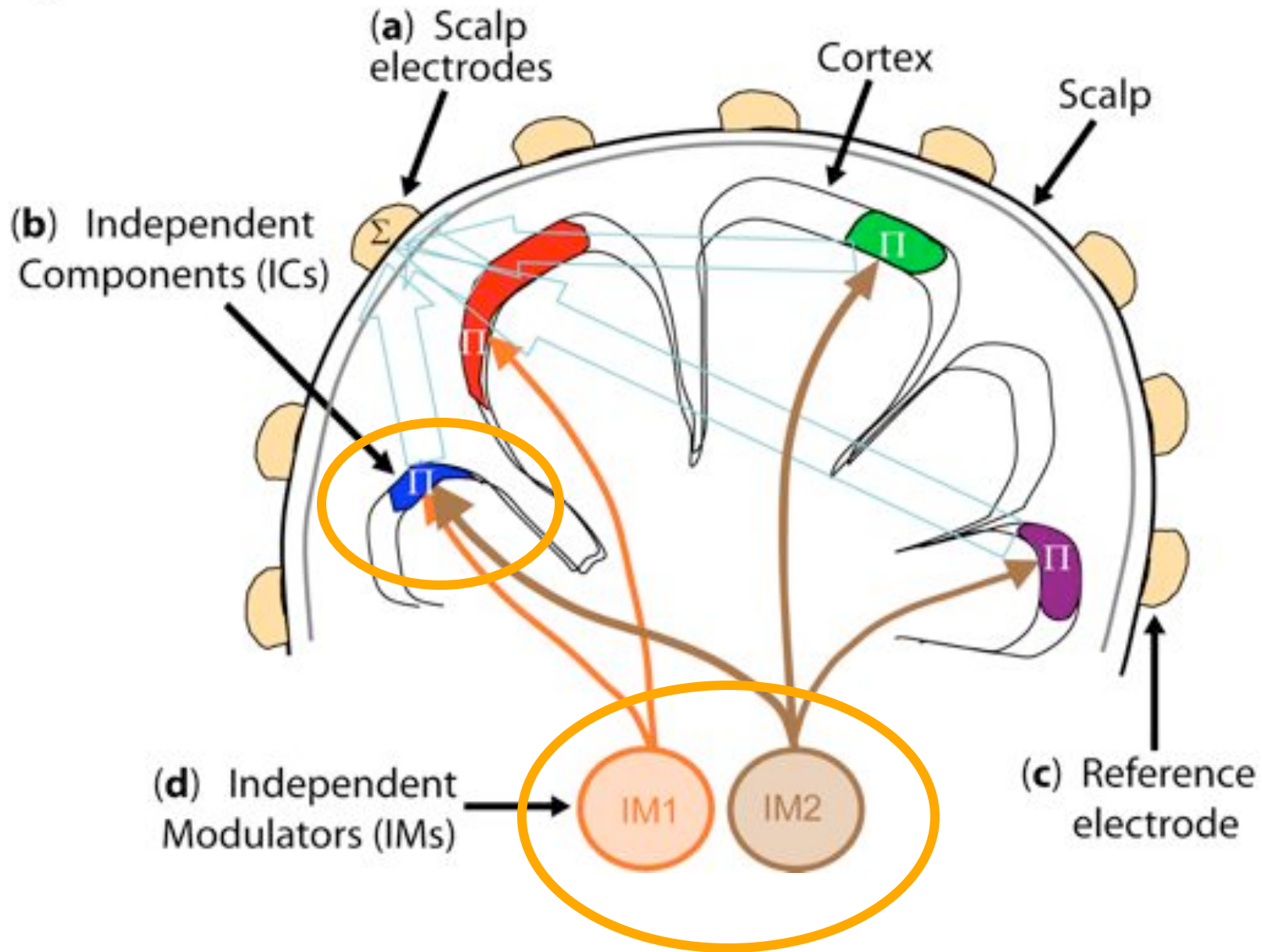
EEG States of Emotion Imagination

Suggest the imaginative experience of 15 different emotions:

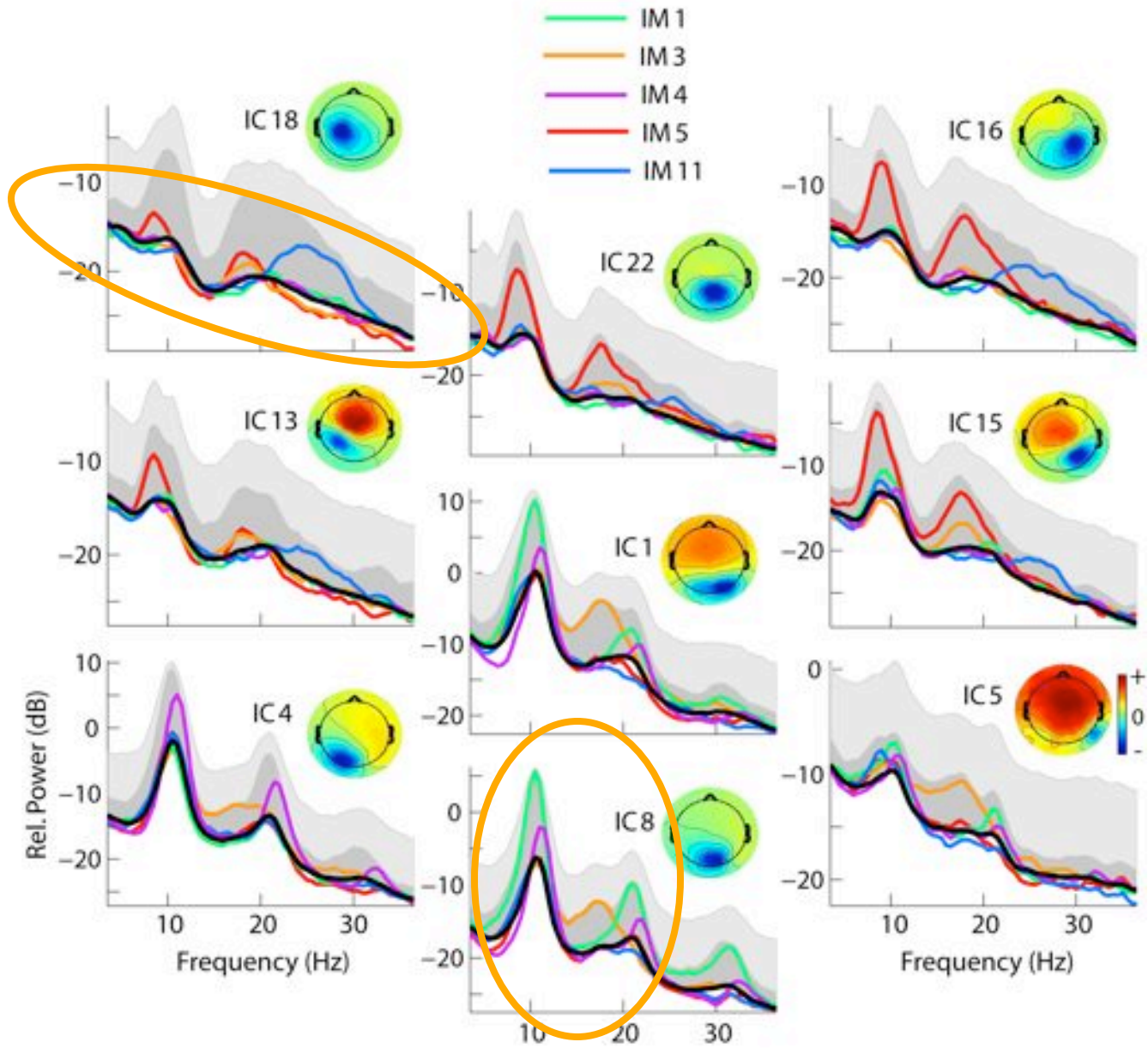
- initial relaxation
- alternate positive and negative emotions
- relaxation between emotion episodes
- obtained 1-5 min periods of eyes-closed spontaneous EEG
- 33 subjects



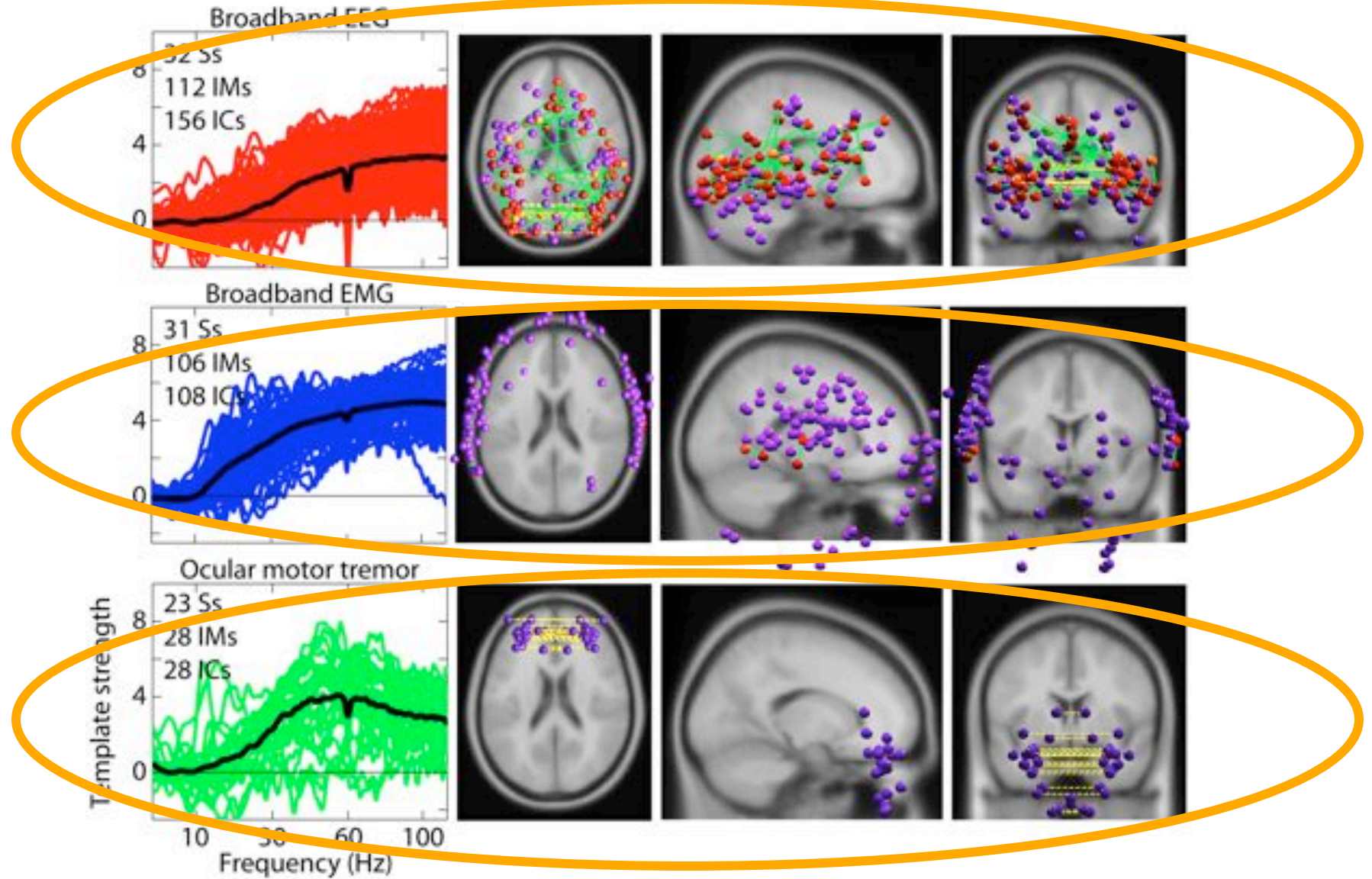
Independent Modulators



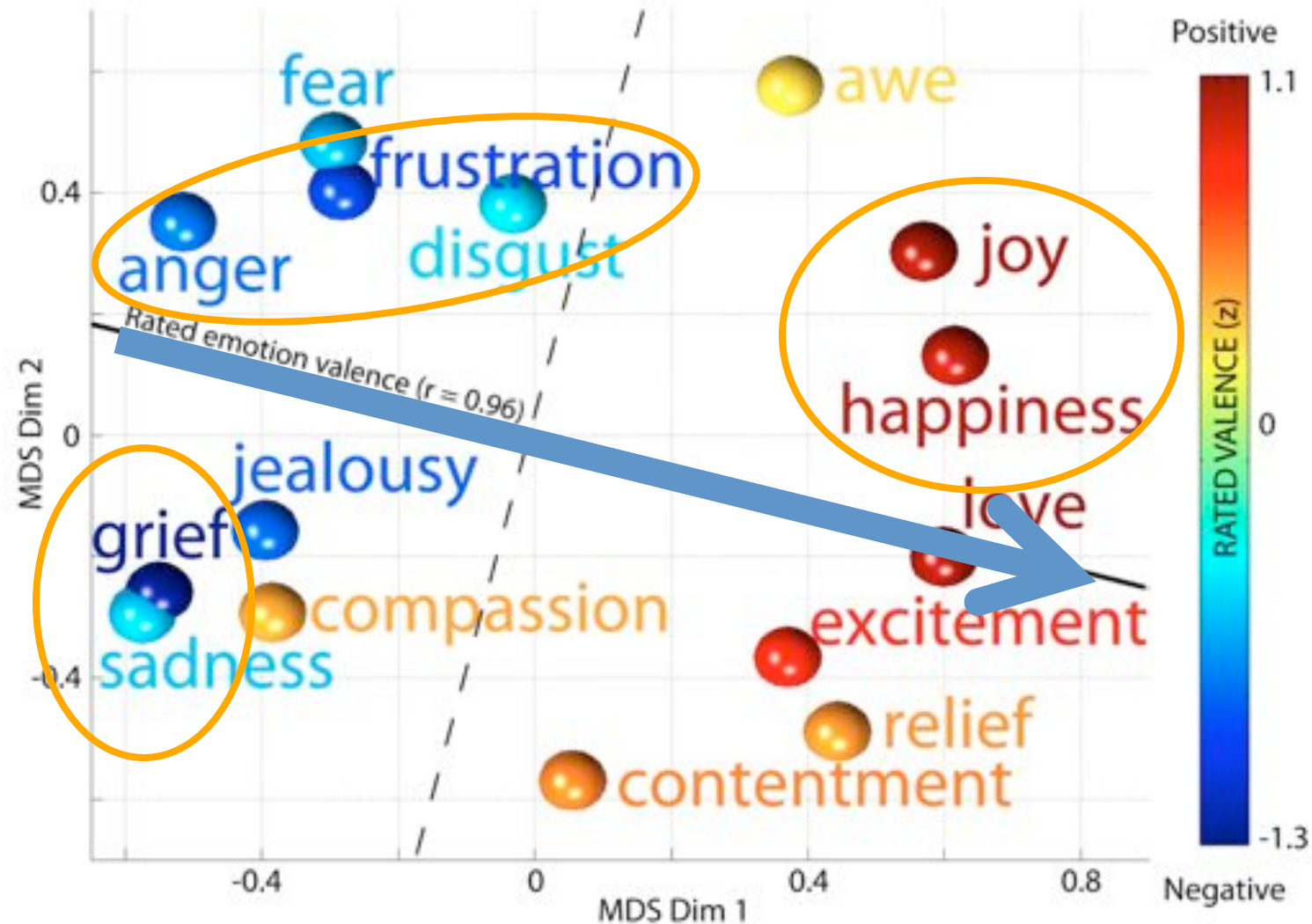
Independent modes of spectral modulation



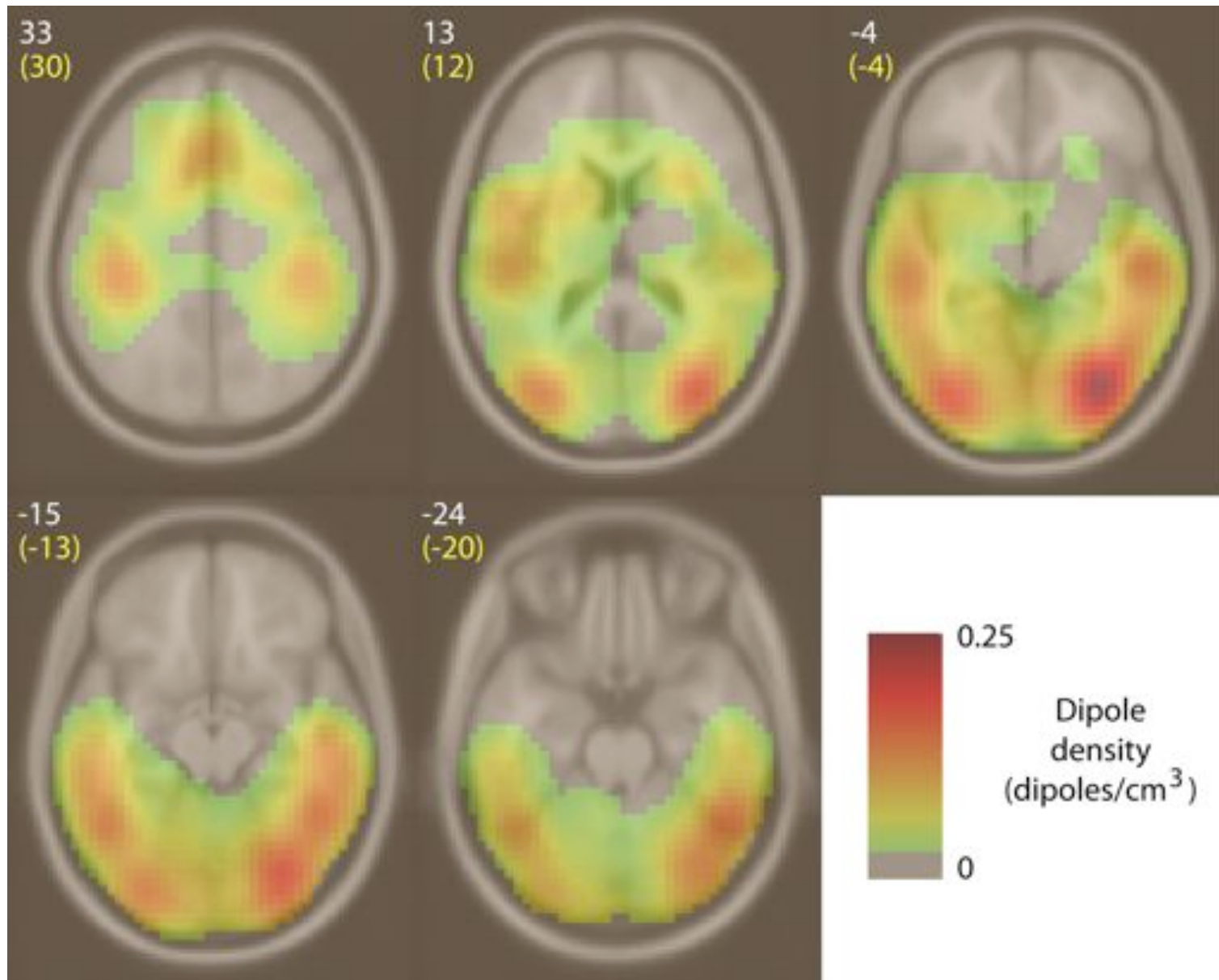
Broadband high-frequency modes



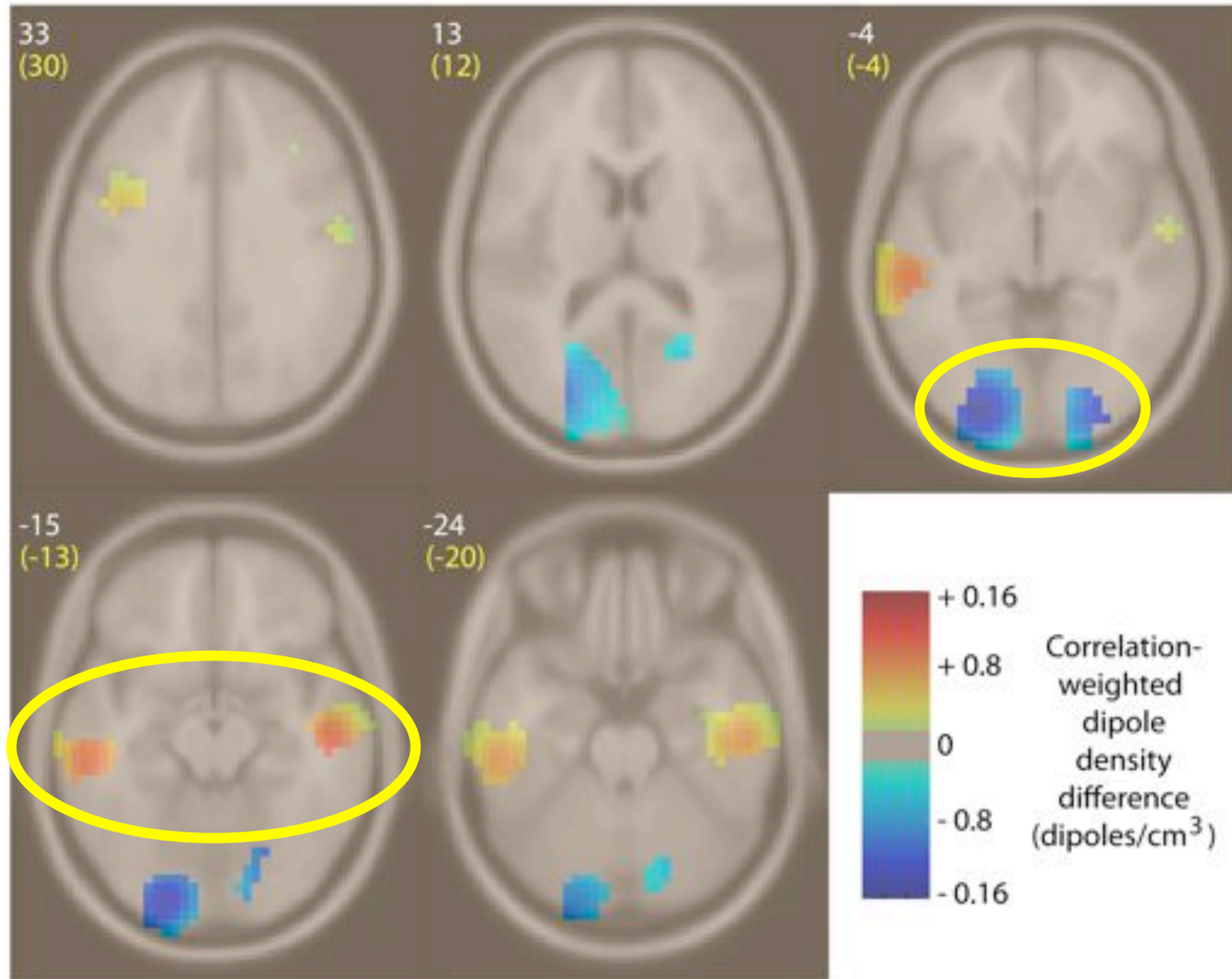
Changes in broadband power with imagined emotion



Distribution of broadband modes



Positive and negative valence modes



Just: A Suite for Flute, Violin, Cello, and Brain

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

Distributed Brain Dynamic Events

Who Dam It?

I realized that ...

It struck me that ...

I wondered if ...

All of a sudden ...

The feeling hit me that ...

I looked to see if ...

I noticed that ...

I looked again at

I decided that ...

It occurred to me that ...

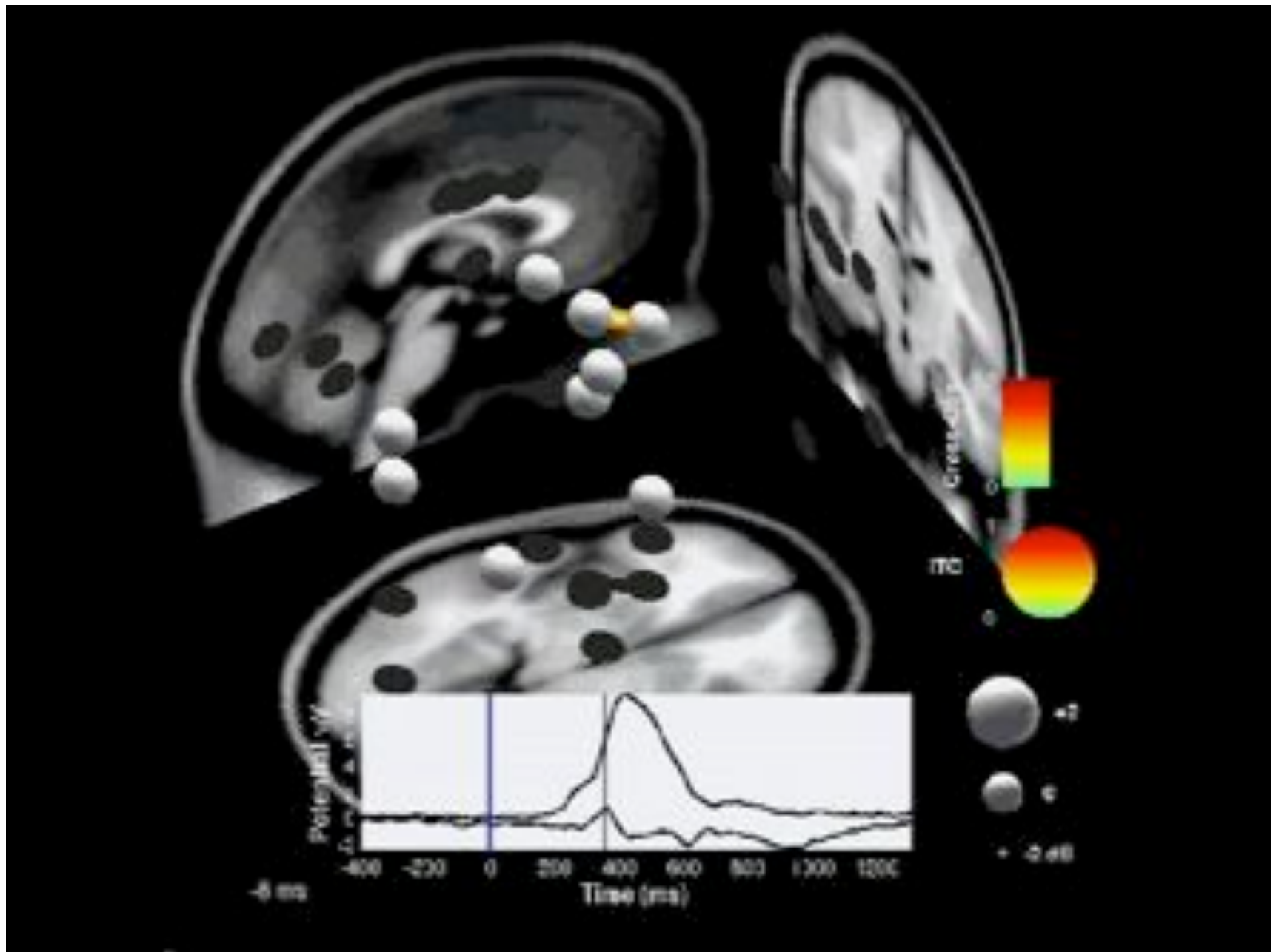
I imagined ...

I searched my memory for ...

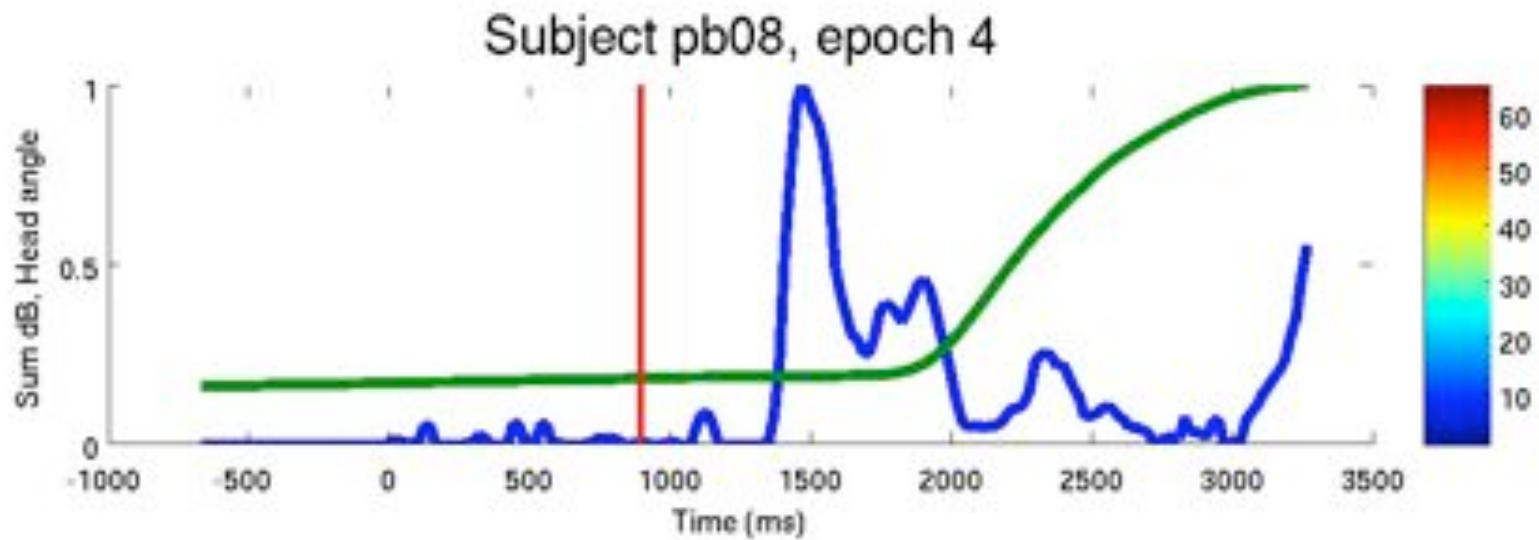
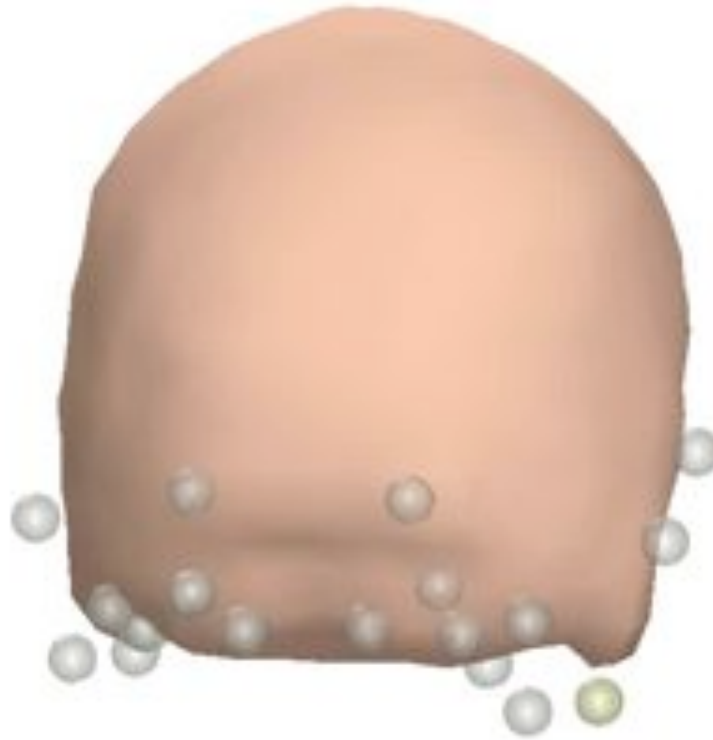
Distributed

Brain Dynamic

Events

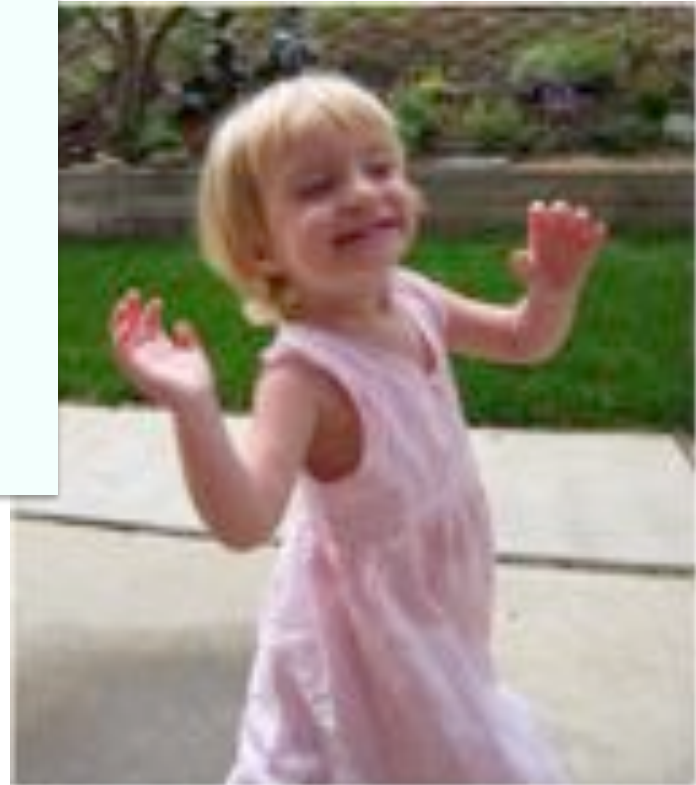


Distributed muscle / movement events



Human Agency & Embodied Cognition

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



A man in a white lab coat is shaking hands with another person. The man in the lab coat is smiling and looking towards the camera. The background is a plain, light-colored wall.

**The brain & body *together* respond
to the challenge of each moment.**

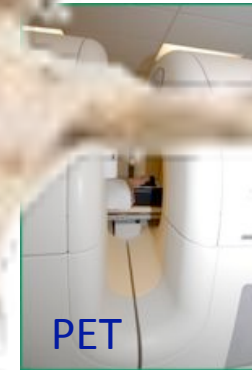
Mobile Brain/Body Imaging

But human brain activity during natural
motor actions and interactions
in 3-D space

has never been observed or modeled !

Brain imaging during natural behavior ?

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



Why?

- In all modalities but EEG, sensors are **heavy**.
- Muscle and movements contribute ('noise') signals.

- But this limitation is highly artificial.** Nearly all our life involves *active movements and interactions* within a 3-D environment.
- **Brain activity during free movement in 3-D space has never been observed or modeled!**

M I C R O



SPIKES

LFP

ECOG

EEG

MACRO

~1 MHz

?

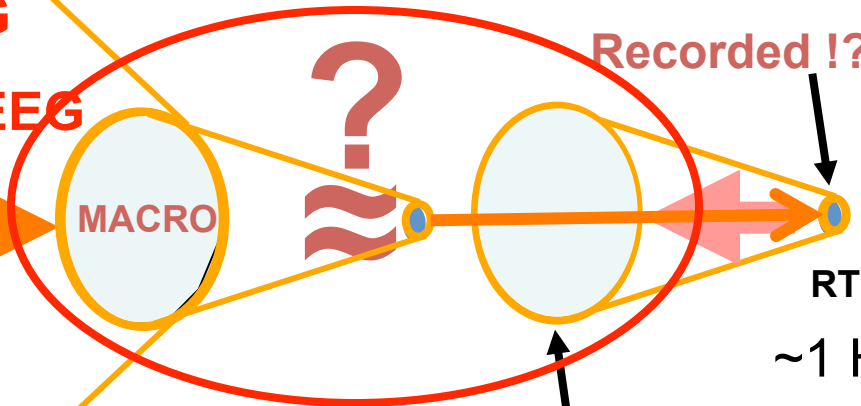
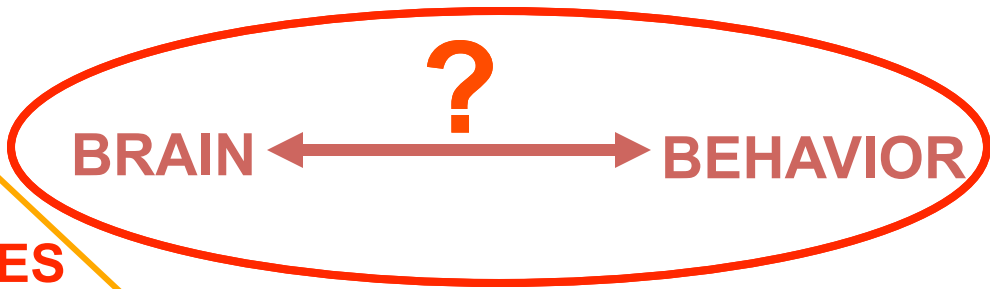
Observable

?? Hz

Recorded !?

RT

~1 Hz



~1,000,000 GHz

M

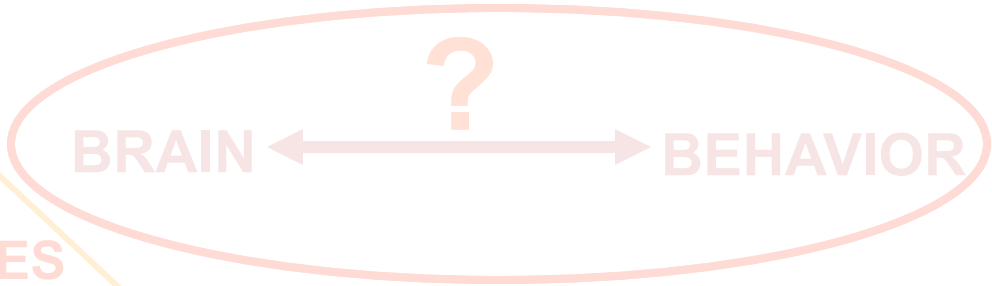
I

C

R

O

MOBI



SPIKES

LFP

Recorded !?

RT

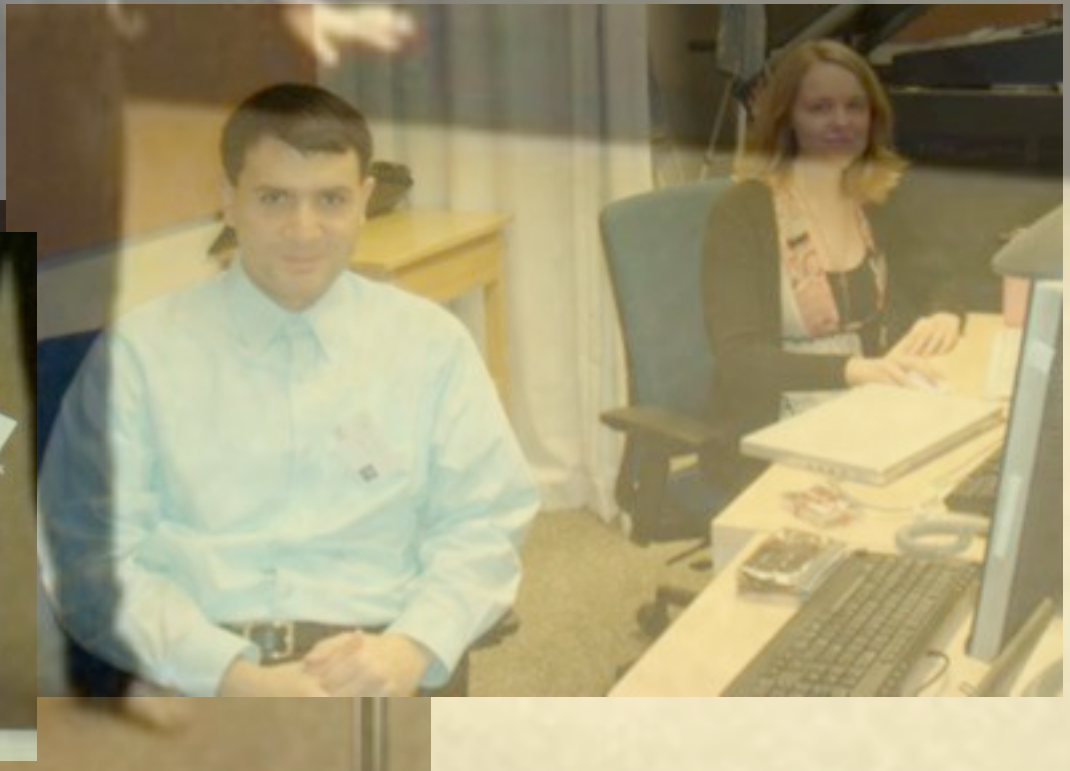
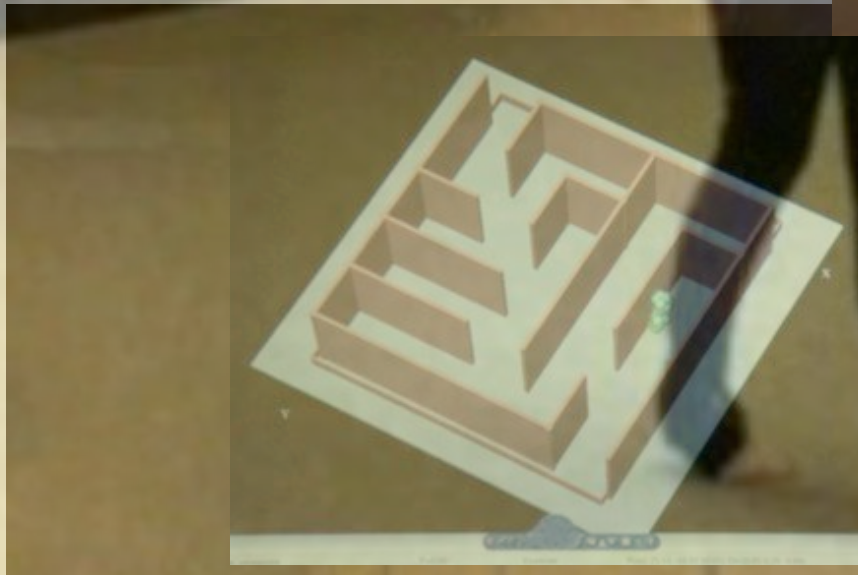
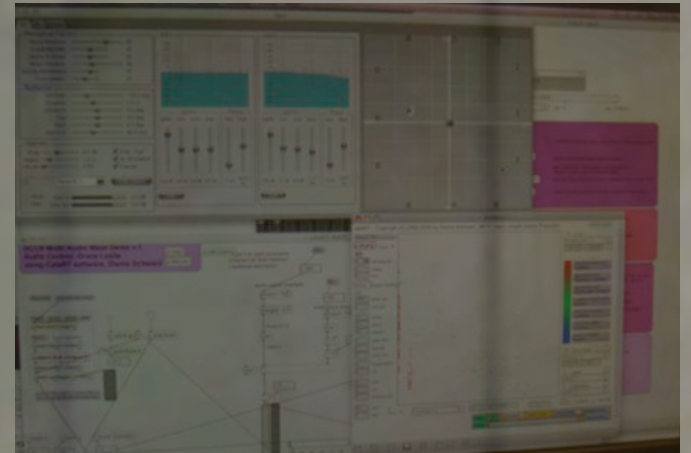
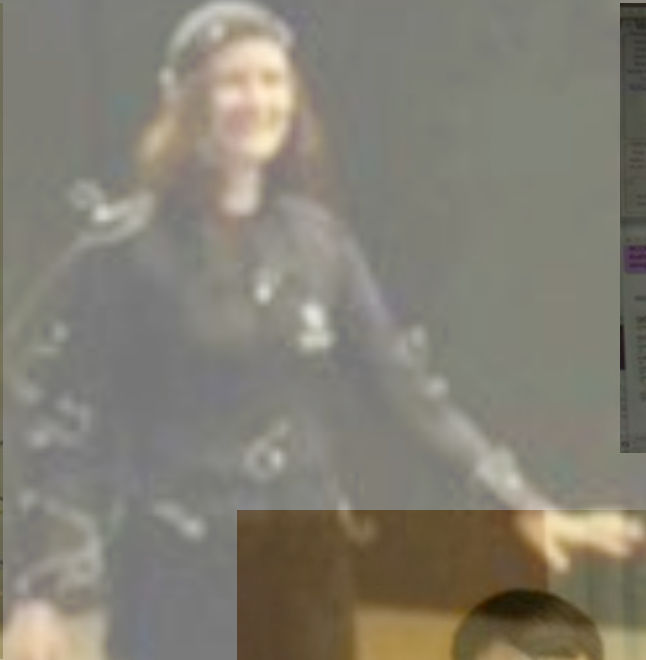
1 Hz

~1,000,000 GHz

Mobile Brain/Body Imaging

- Record what the brain does,
- What the brain experiences,
- And what the brain controls.

MoBI Lab at SCCN, UCSD



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

MoBI Systems for Cognitive Monitoring



- Alertness
- Arousal
- Attention
- Anticipation
- Agency
- Affect



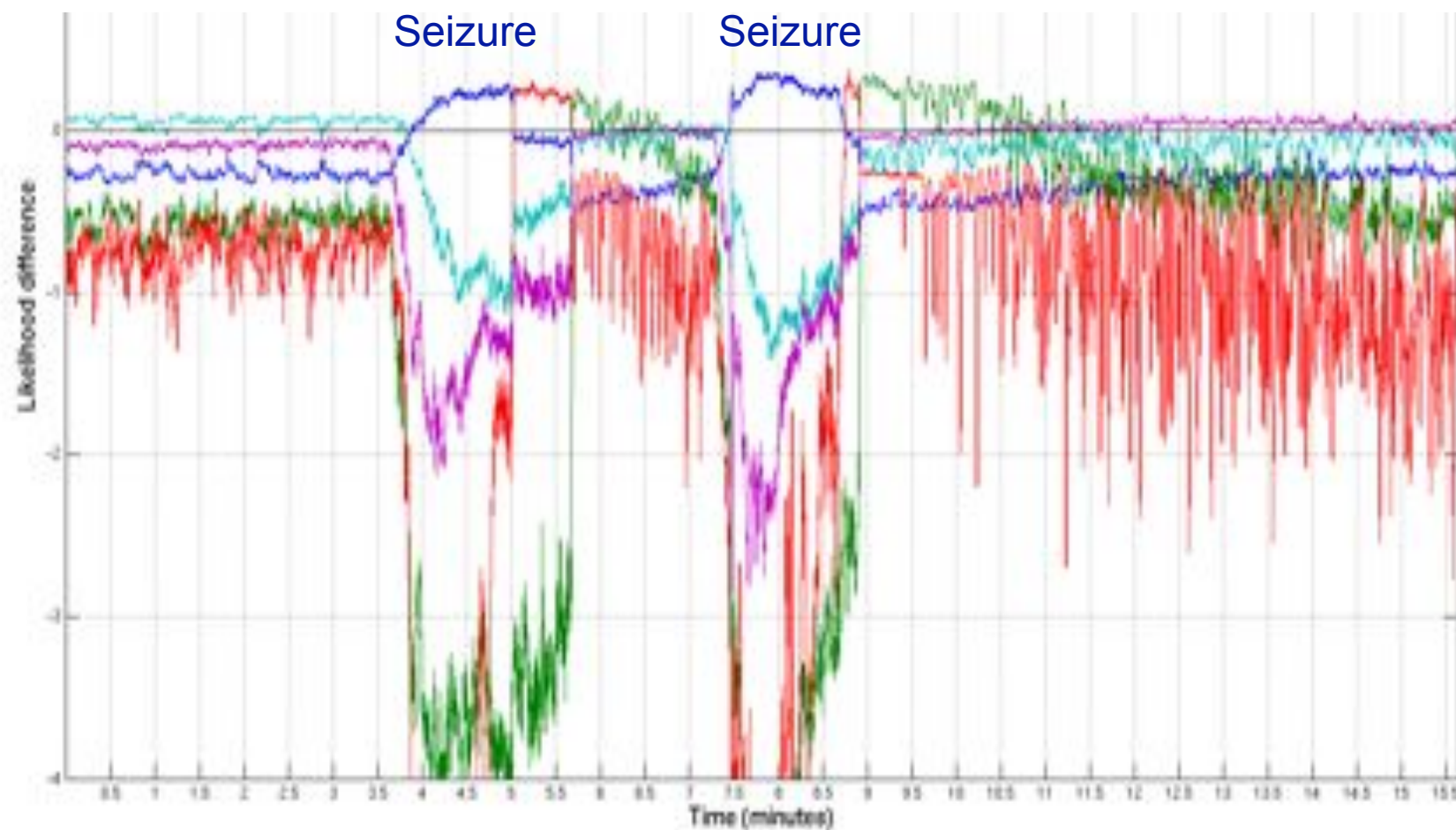
Brain-Computer Interface (BCI) Systems for willed control ...



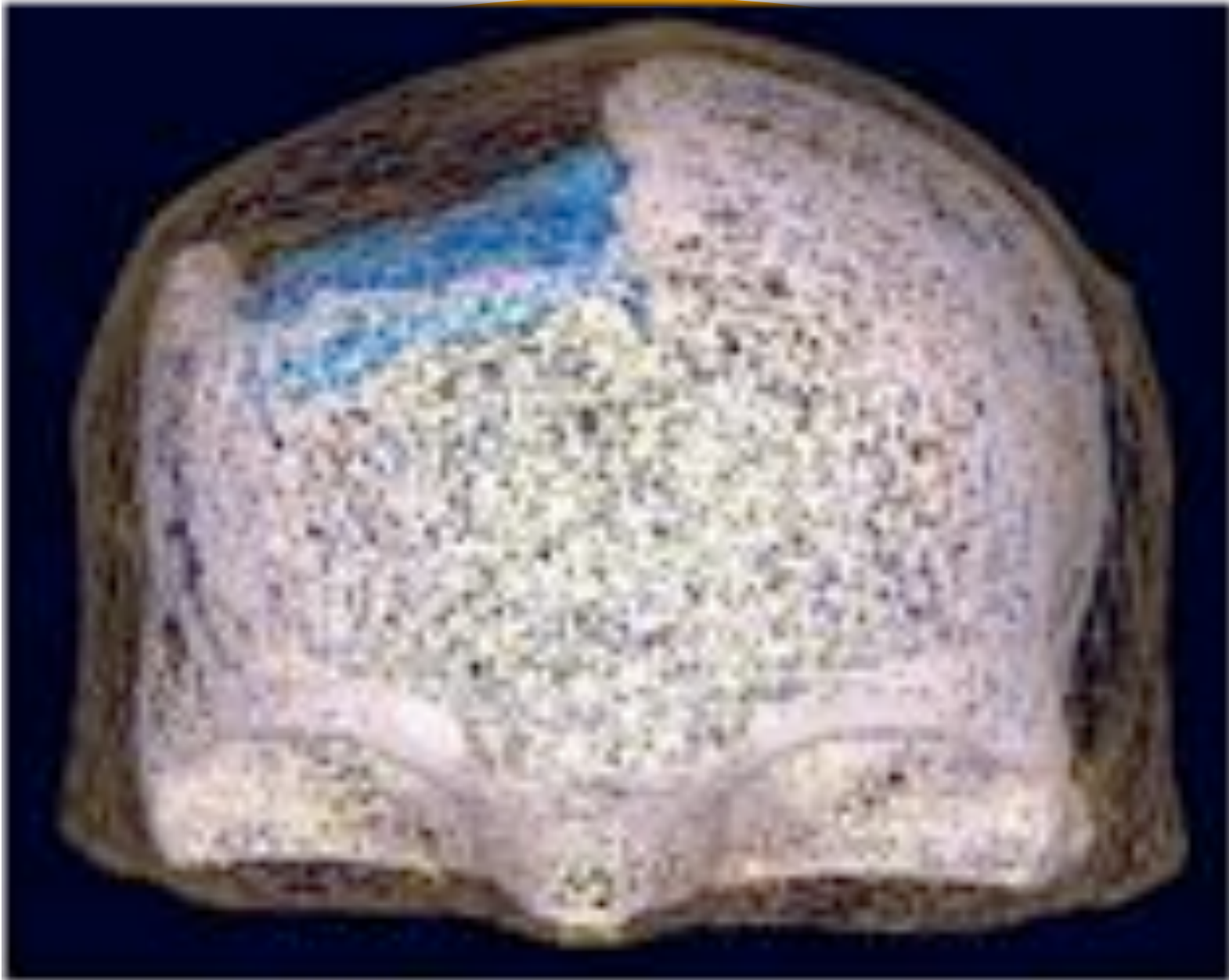
Electrocortical source imaging (ESI) systems for clinical research, diagnosis, and treatment

- EEG & MoBI are low-cost relative to other brain imaging systems;
- This allows future wide distribution of these systems,
- And their use in very large research studies.
- Very large online data resources are possible (HeadIT);
- These may be improve the speed and quality of BCI,
cognitive monitoring, and clinical imaging systems.
- Extremely high-density EEG & MoBI imaging systems are possible;
- These may allow new discoveries – in electro-accupuncture, etc.

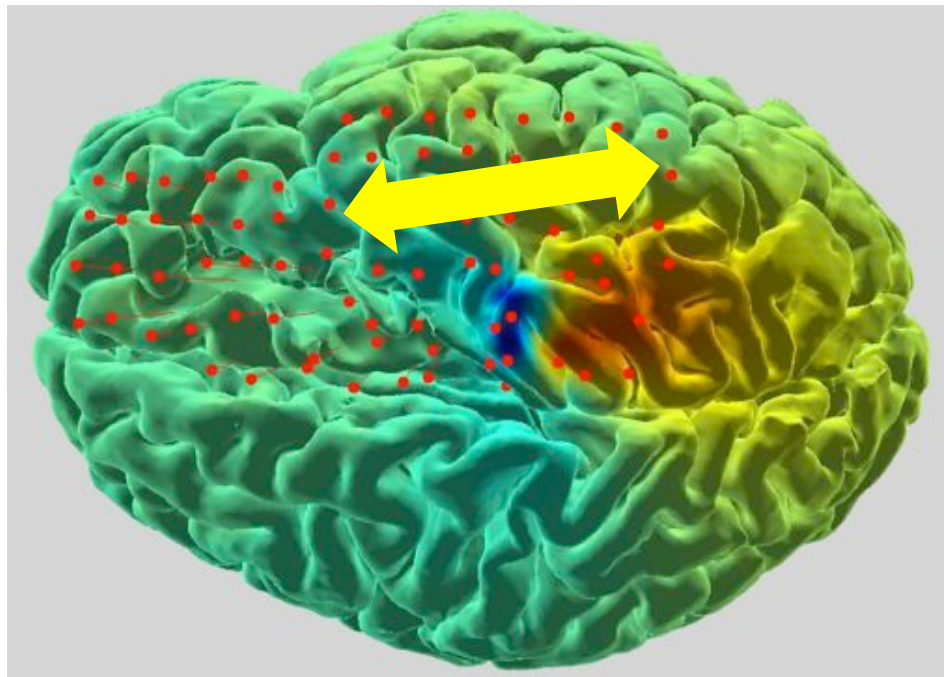
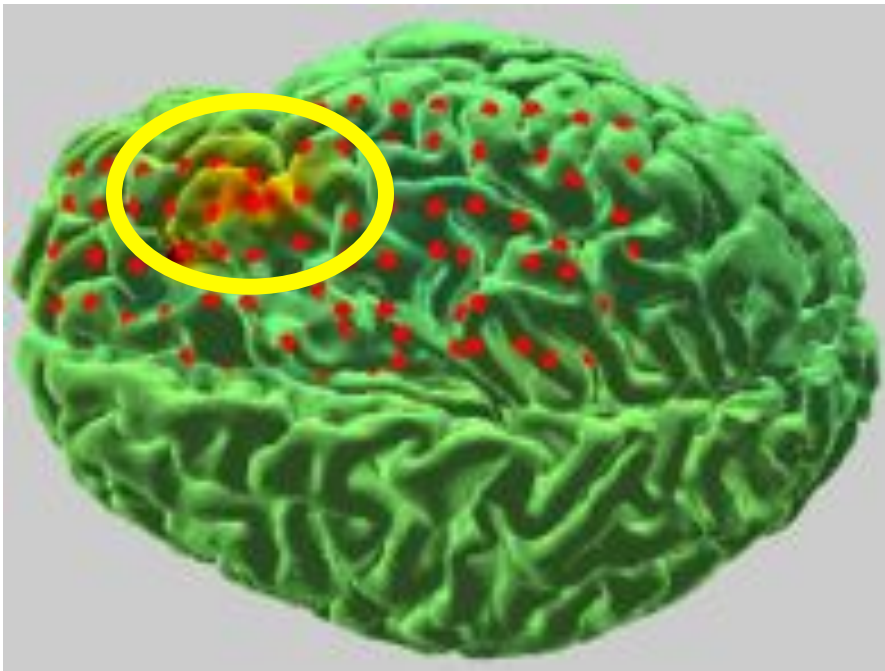
Electrocortical source imaging (ESI) systems for clinical research, diagnosis, and treatment



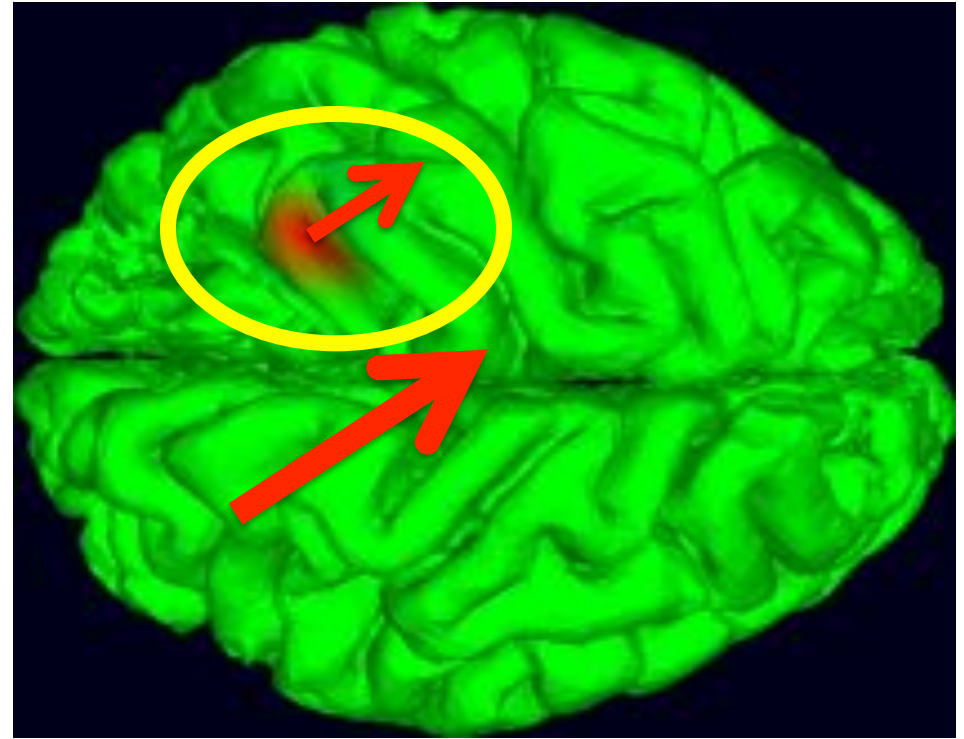
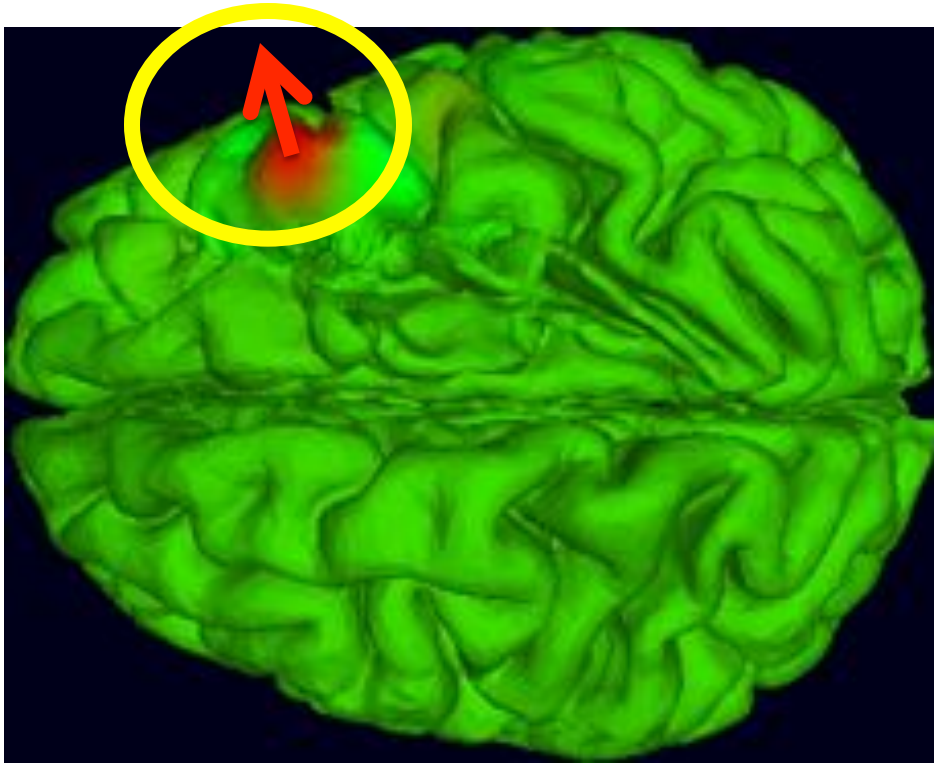
Electrocortical source imaging (ESI)



Electrocortical source imaging (ESI)



Electrocortical source imaging (ESI)



Functional EEG brain imaging

Paradigm shift !

→ EEG is something to use, not just something to inspect ...

Goals:

1. Modeling dynamic, distributed brain/body events

to understand how the brain works !

2. Mobile Brain/Body Imaging (MoBI)

for cognitive monitoring.

3. Brain-Computer Interface (BCI)

for willed control.

4. Electrocortical source imaging (ESI)

for medical diagnosis and treatment.

