Event-Related Brain Dynamics I

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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 …

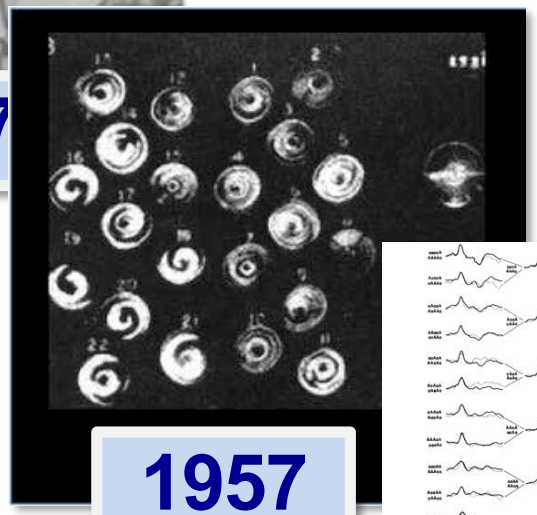
FIGURE 1-2.—Sample of the first EEG tracing taken at the Bradley Hospital, E. Providence, Rhode Island, by H. Jasper and L. Carmichael. Subject: Carl Pfaffmann. Date: July 9, 1934. Record, which shows prominent alpha rhythm of about 11.5 per second, was made with a Westinghouse, galvanometer-type, mirror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

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

S. Makeig 2010

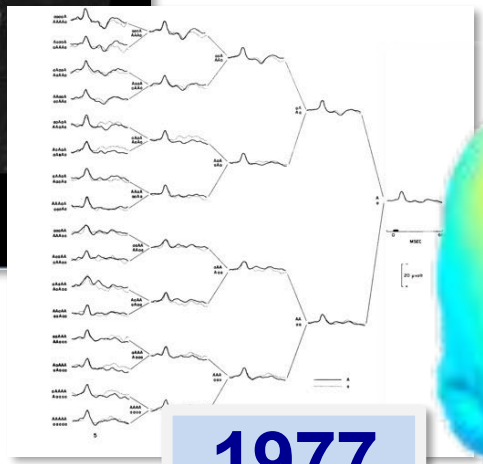
Development of EEG brain Imaging …

1937



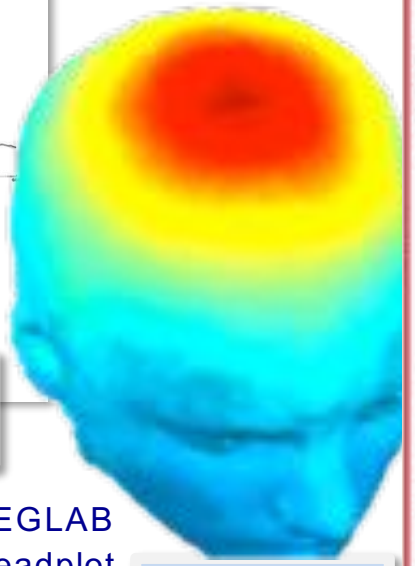
1957

Toposcope
Grey Walter



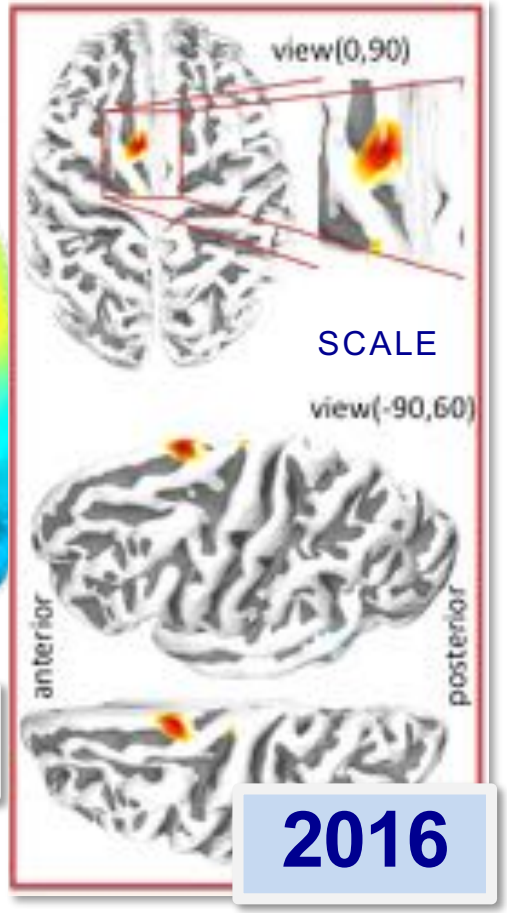
1977

Oddball ERPs
K. Squires et al.



EEGLAB
headplot

1997



2016

Z. Akalin Acar et al.

Functional Brain Imaging

Hemodynamic imaging

= imaging local brain

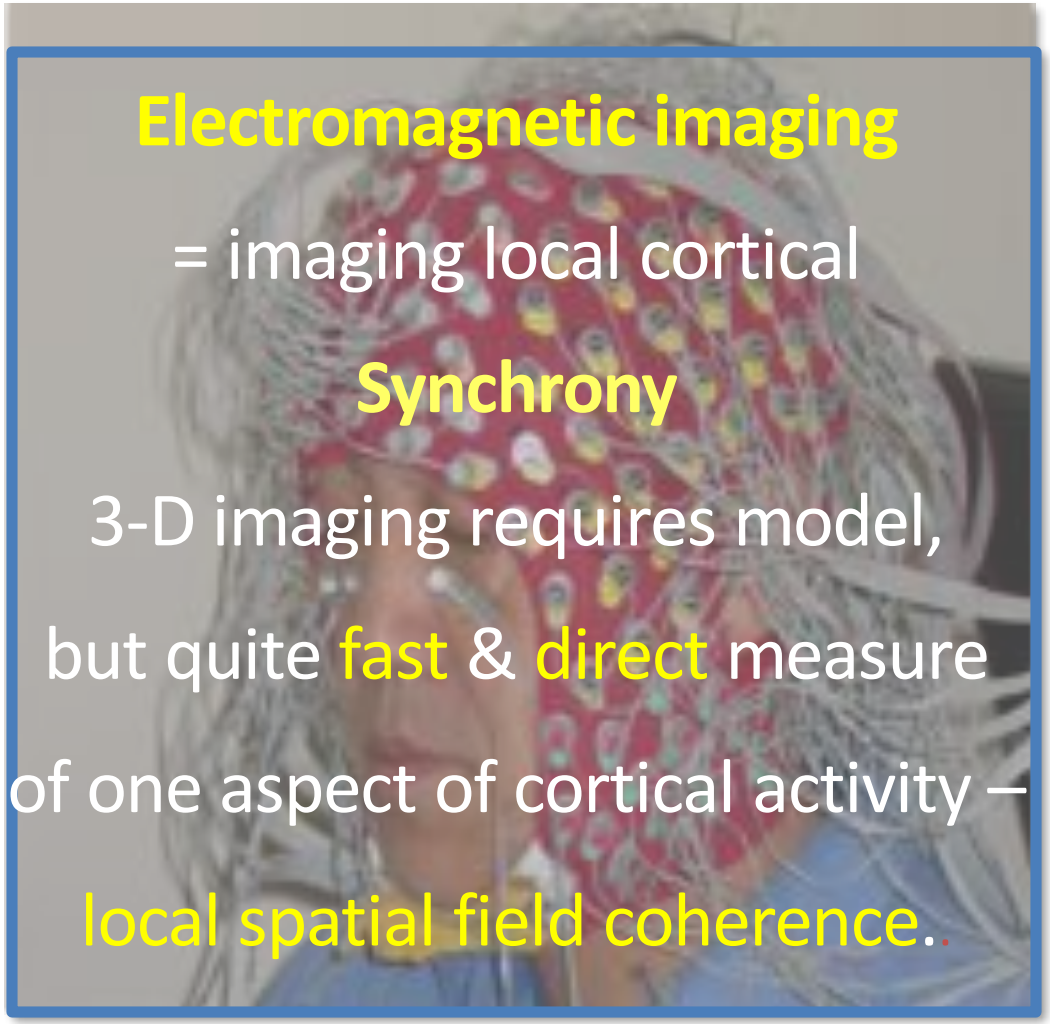
Energy

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..

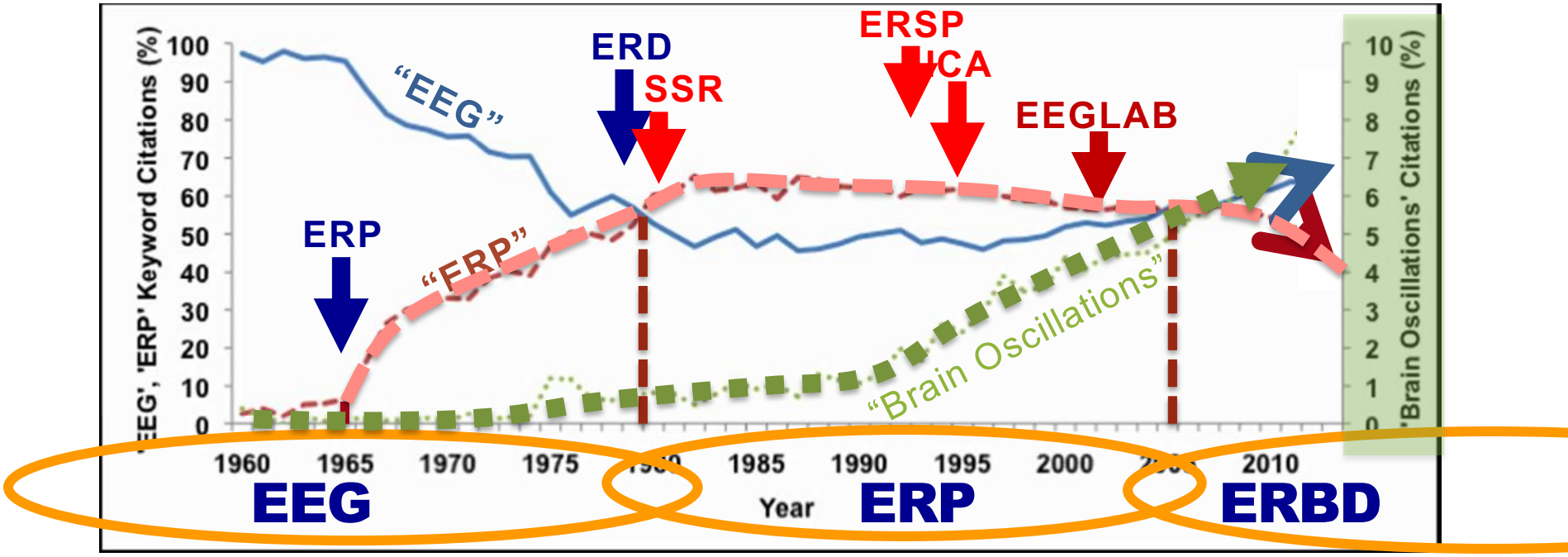
Advantages of Functional Brain Imaging using EEG

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

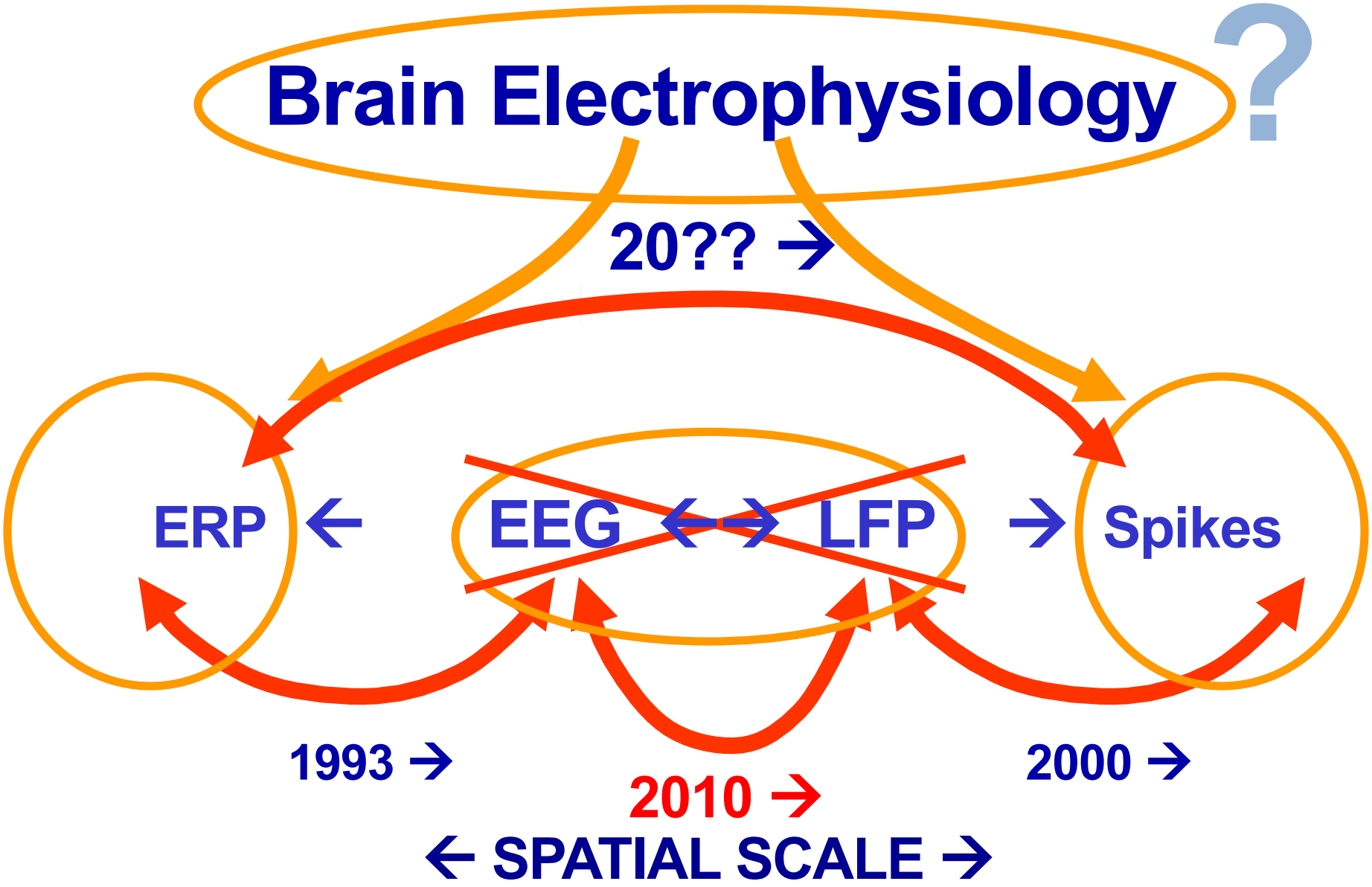
Three Modern Eras of EEG Research



Loo, Lenartowicz & Makeig, 2015

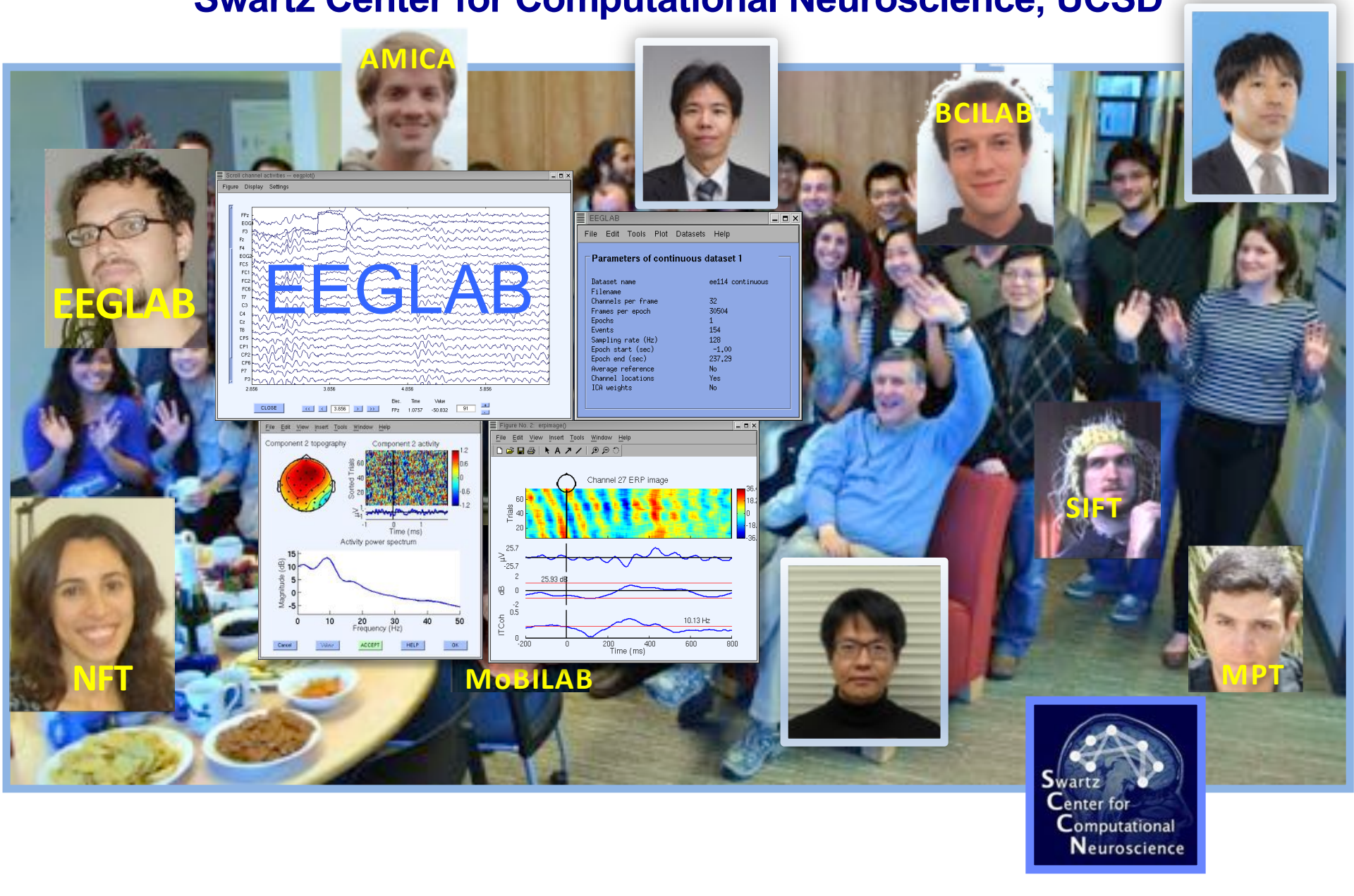
Figure 1. Relative number of PubMed citations retrieved by 'All Fields' search terms: 'EEG,' 'ERP,' and 'Brain Oscillations.' The percent of citations for each search term relative to the total number of citations returned by a search for any of the three terms is plotted relative to the other two search 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



S. Makeig, *TINS* 2002

Swartz Center for Computational Neuroscience, UCSD

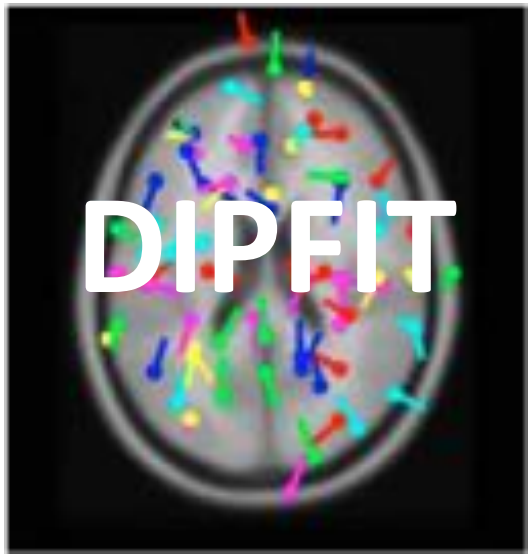


10th Anniversary SCCN Impromptu celebration 1/2/12

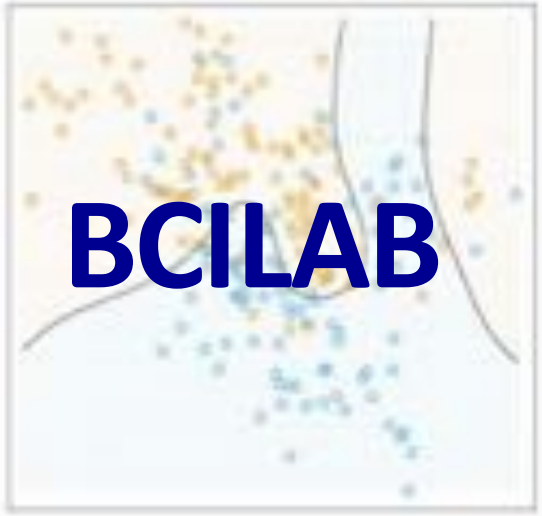
List of data import extensions

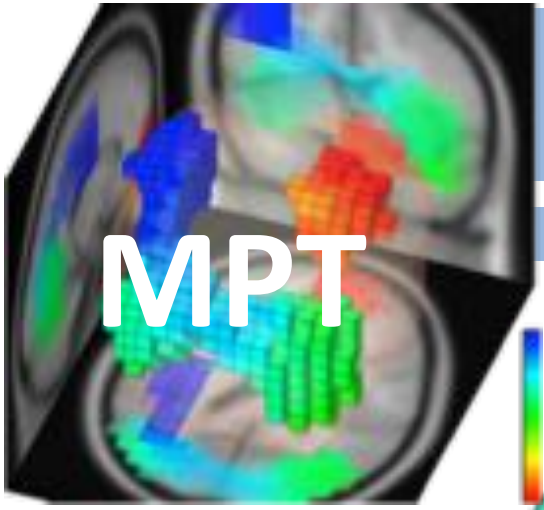
Plug-in name	Version	Short plug-in description	Link	Contact	Comments
MFFimport	1.00	Import MFF files from the EGI company	Download	S. Chennu	User comments
ANTeepimport	1.10	Import ANT .cnt data and trigger files	Download	M. van de Velde	User comments
BCI2000import	0.36	Import BCI2000 data files	Download	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	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	D. Callen	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

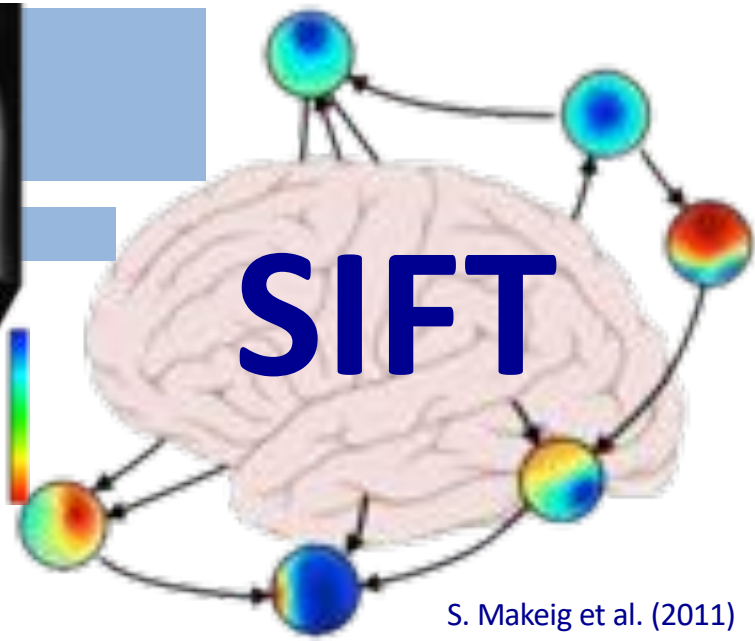
EEGLAB EXTENSION MANAGER



EEGLAB Plug-In Extensions







S. Makeig et al. (2011)


Who
am I?

Embodied Agency

Brain processes

have evolved and function

to optimize the ***outcomes***

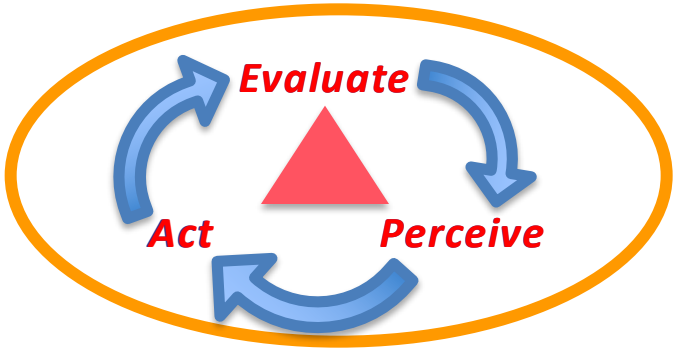
of the ***behavior***

the brain organizes

in response to

perceived challenges

and opportunities.



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

S Makeig 2010

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)

Embodied Agency

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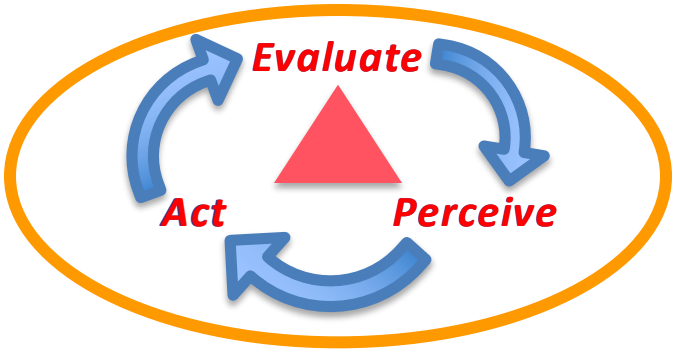


Brains meet the challenge
of the moment
– *every* moment!

EEG & Cognitive Neuroscience

EEG can be used to learn

how the brain and nervous system

supports and sustains human consciousness

In all its aspects --

Knowing

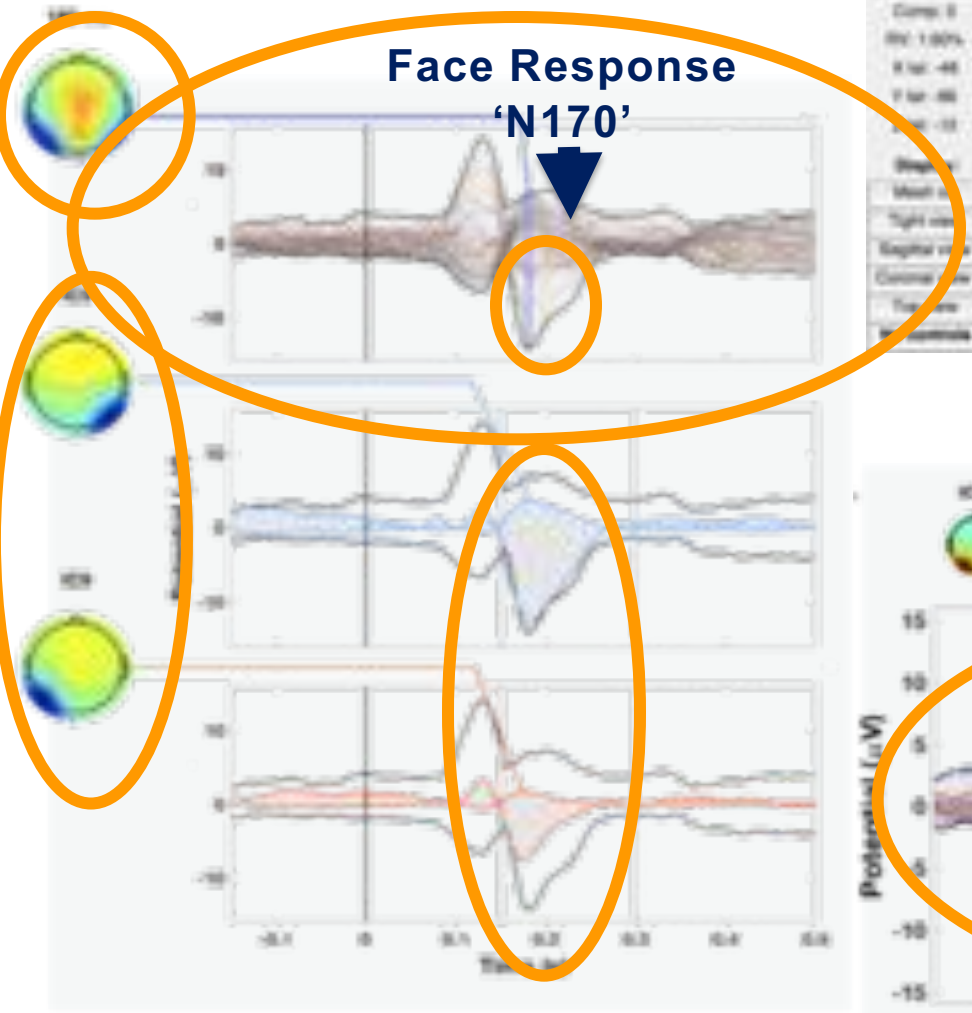
Feeling

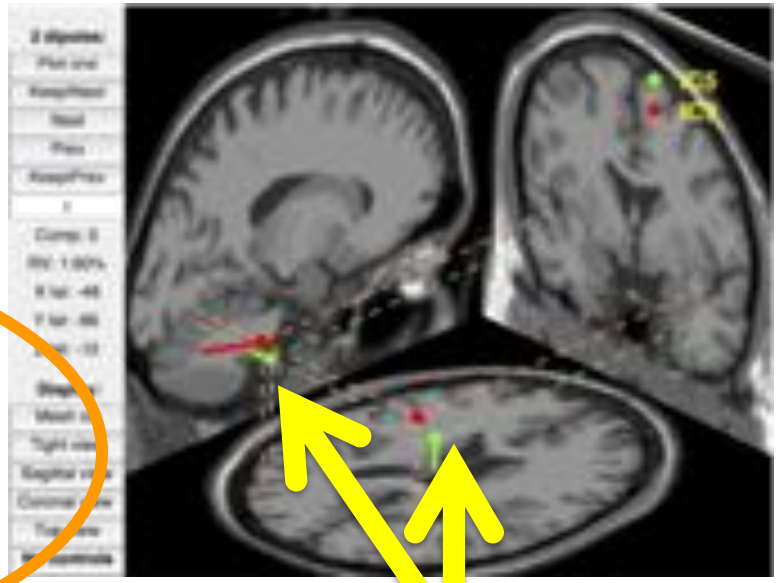
Willing

S. Makeig (2017)

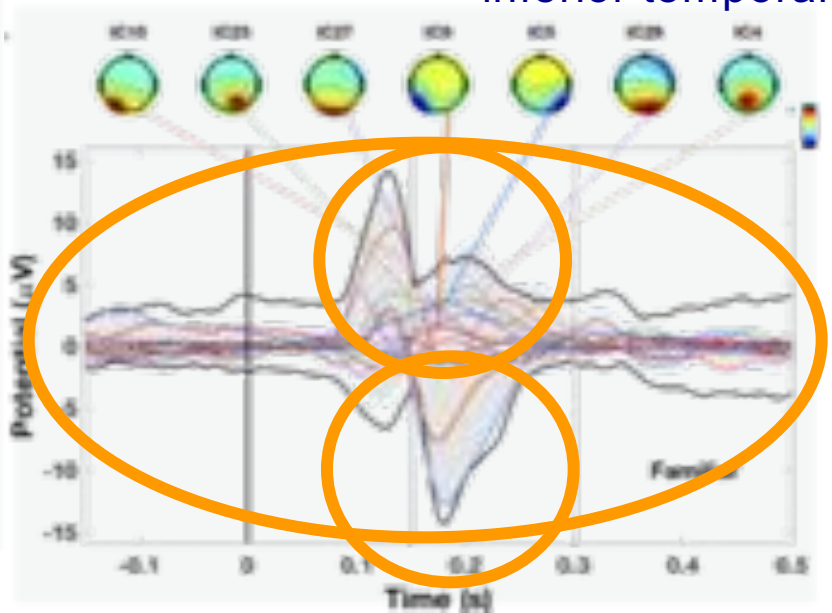
Knowing

- “I see a face photo.”
- “I see a house photo.”





Face area in bilateral inferior temporal cortex



S. Makeig (2017)

Feeling

Emotion Imagination Experiment

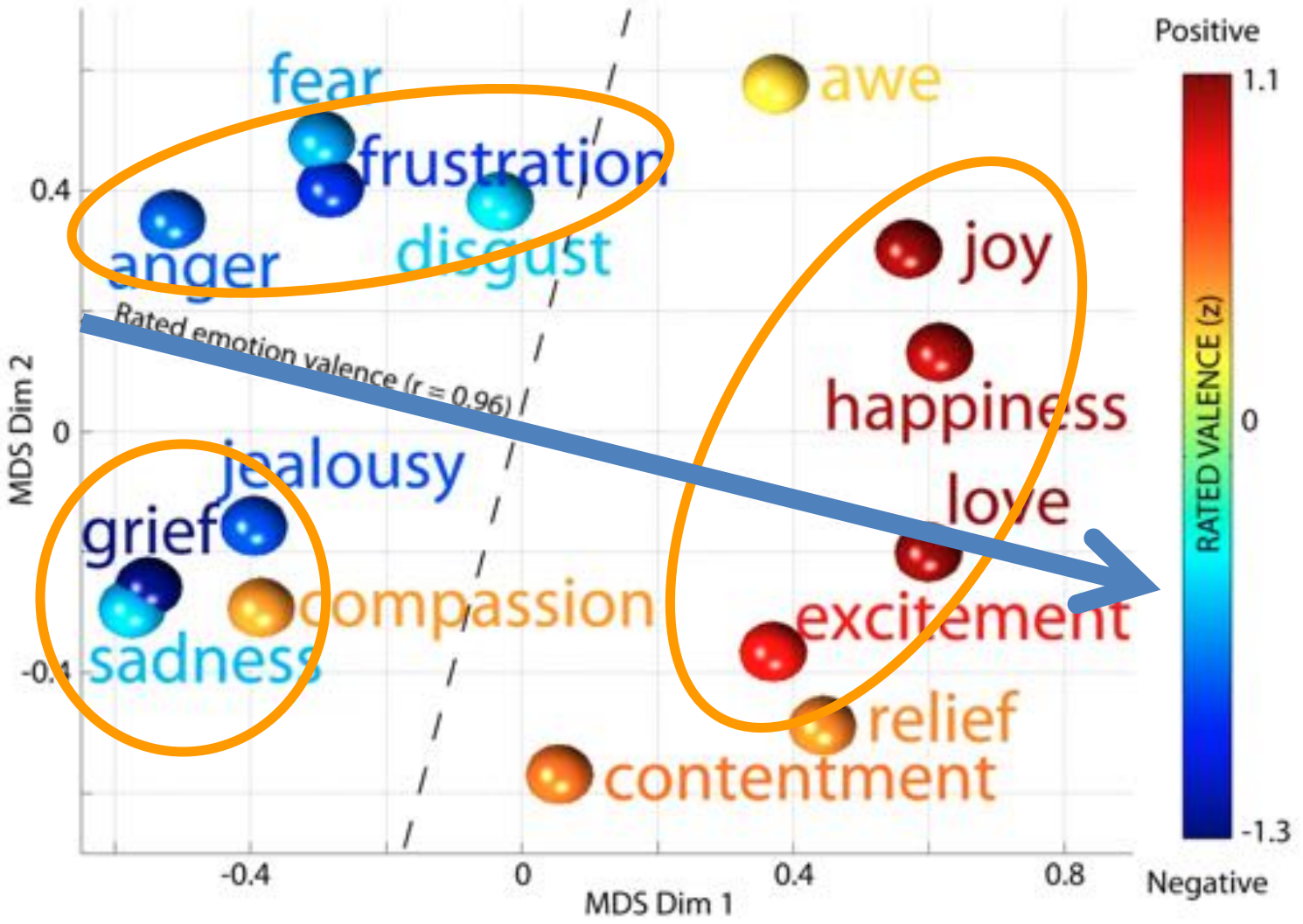
Suggested the eyes-closed experience of 15 different emotions *via guided imagery*.

Collected 1-5 min of continuous high-density EEG data in each emotion state.

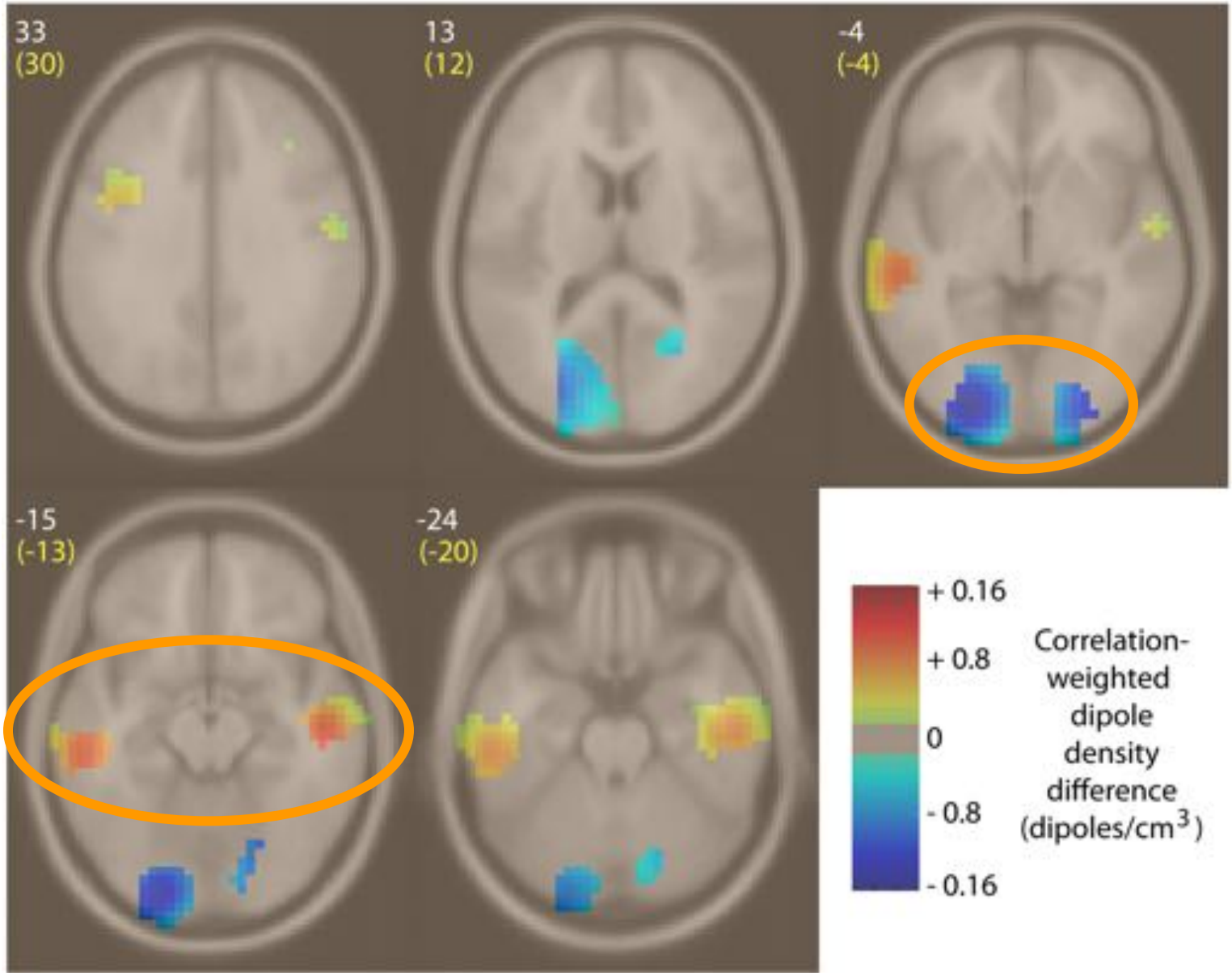
28 subjects

Onton & Makeig, 2009

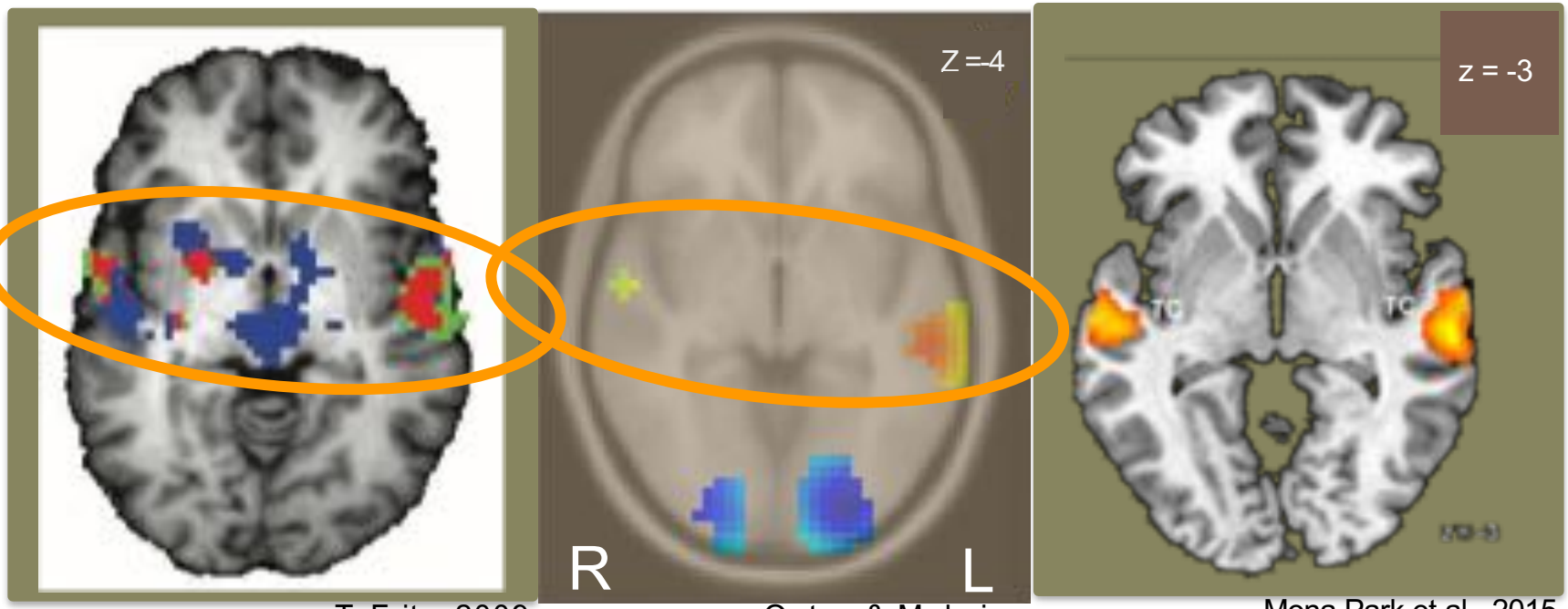
Feeling



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



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



T. Fritz, 2009

Onton & Makeig, 2009

Mona Park et al., 2015

fMRI BOLD

EEG HFB

fMRI BOLD

S. Makeig, 2017

Willing

Imaging Human Agency

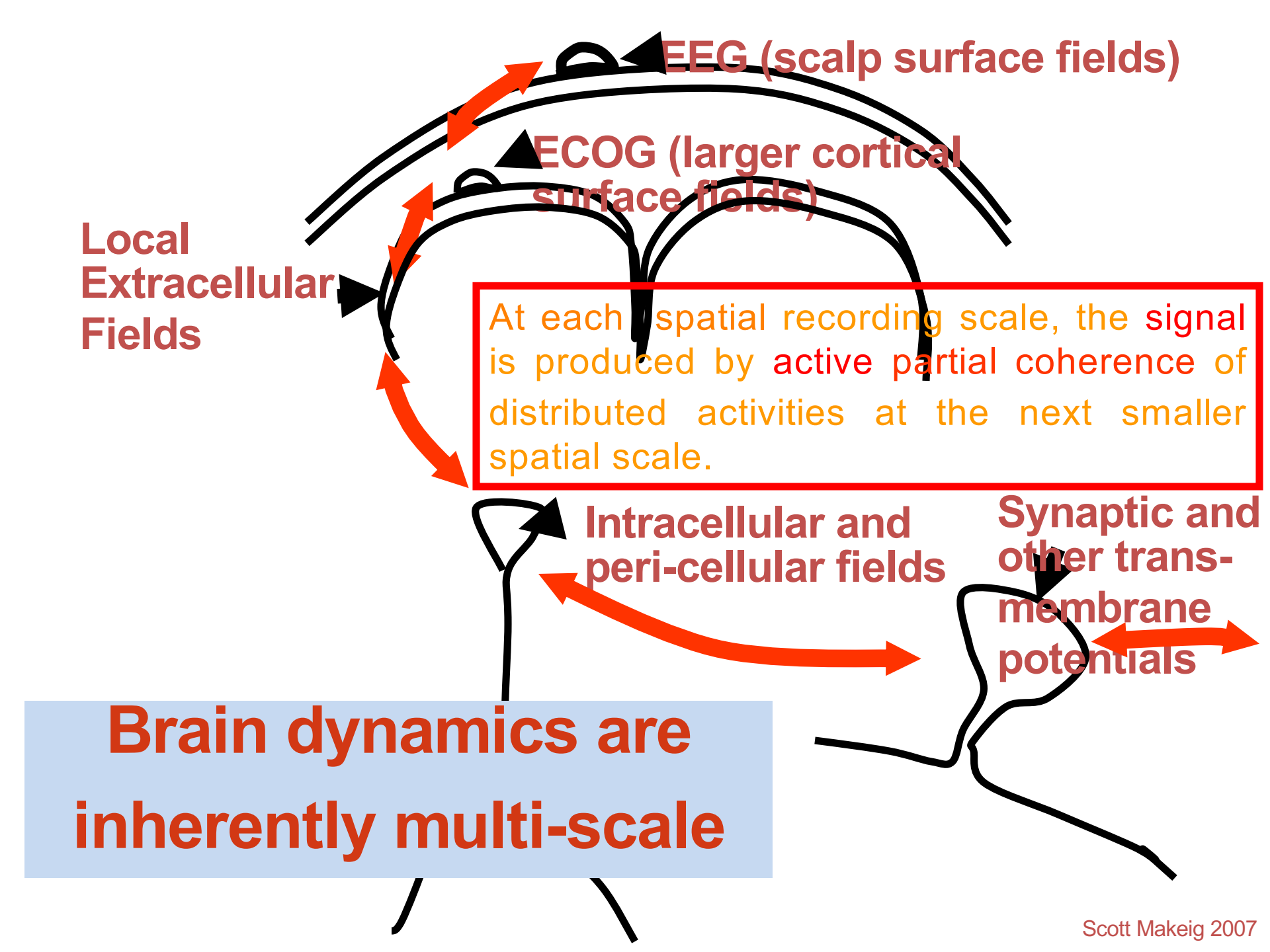
S . Makeig, 2007

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


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)

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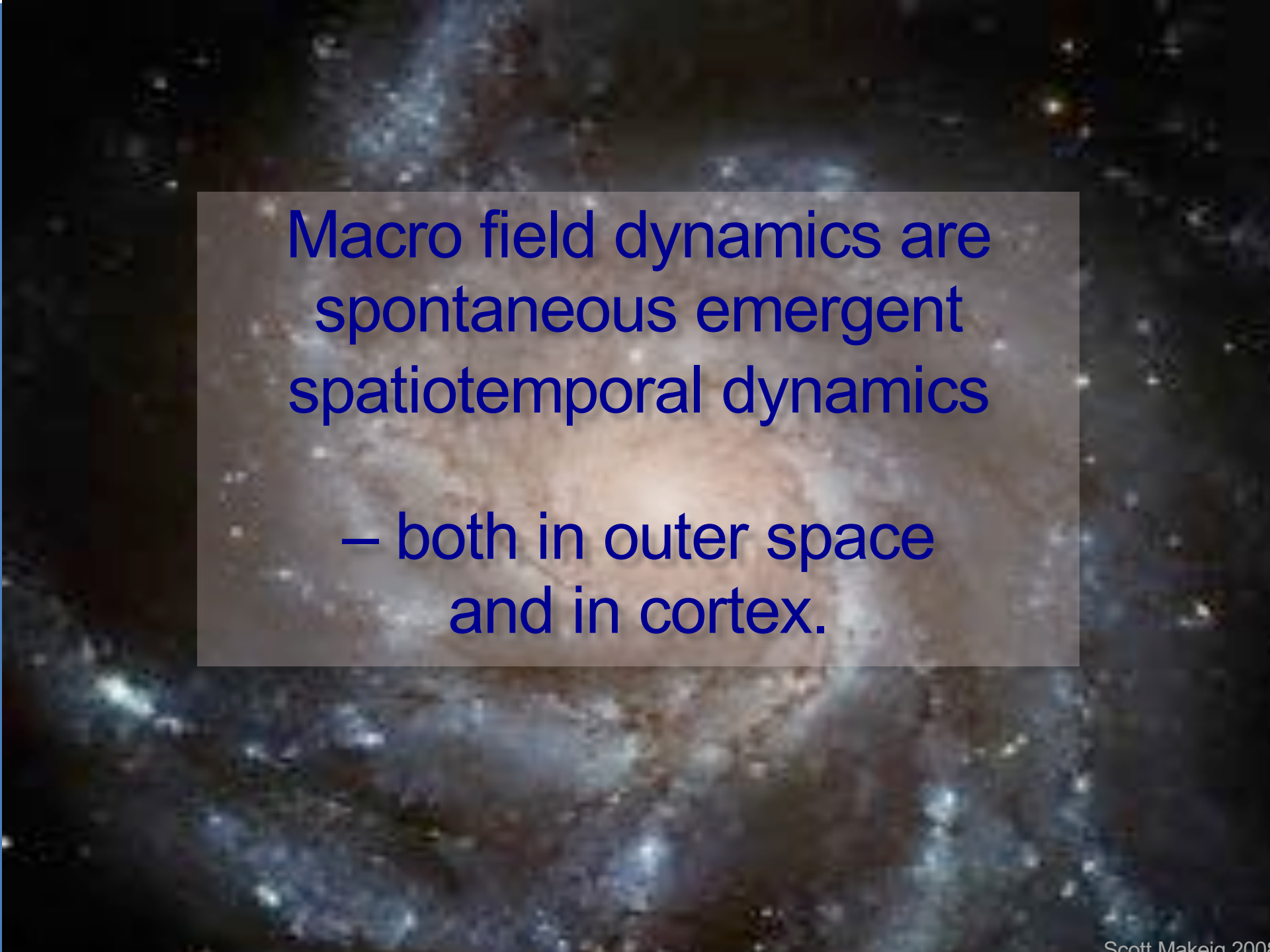
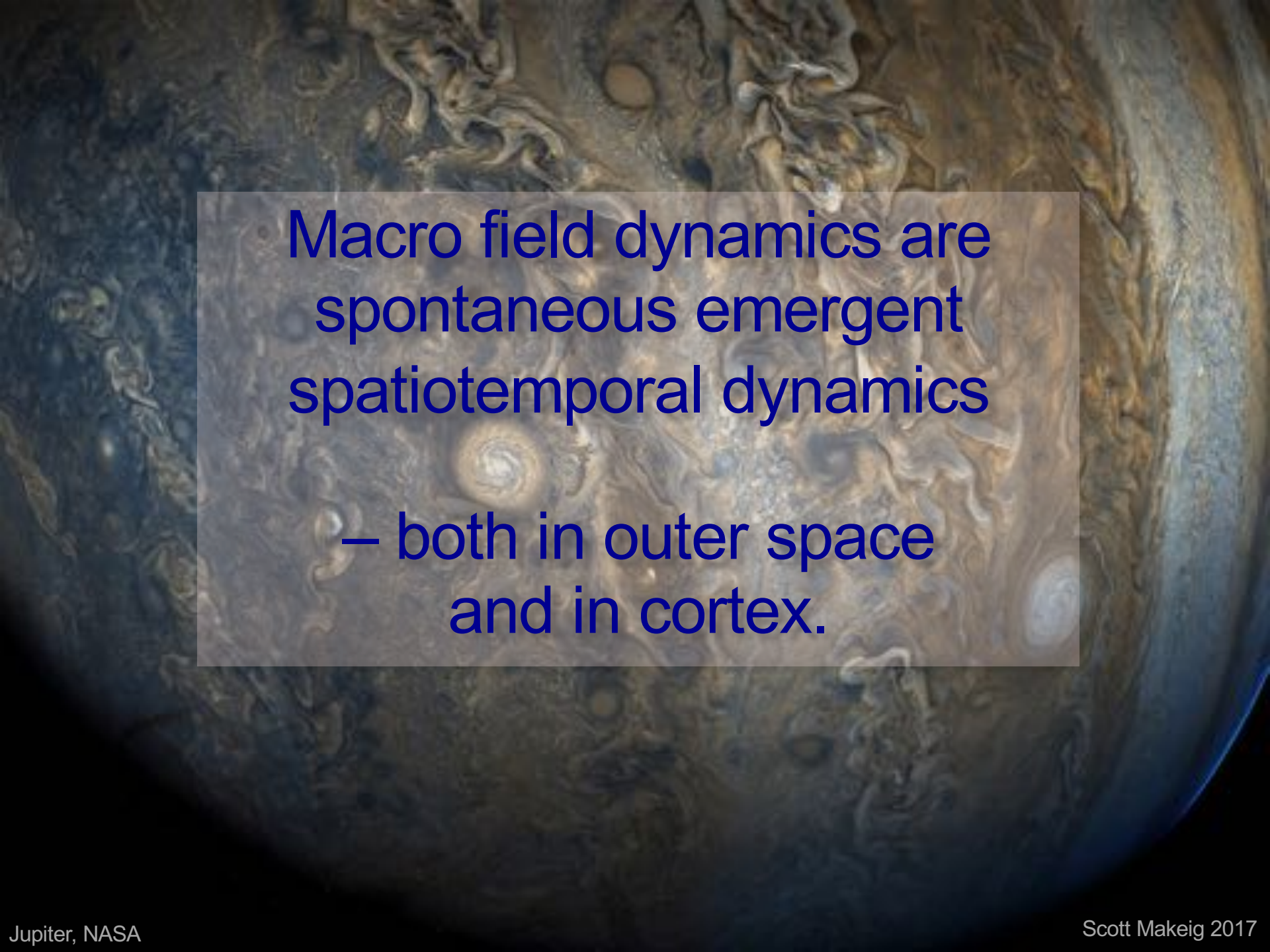
Scott Makeig 2007


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

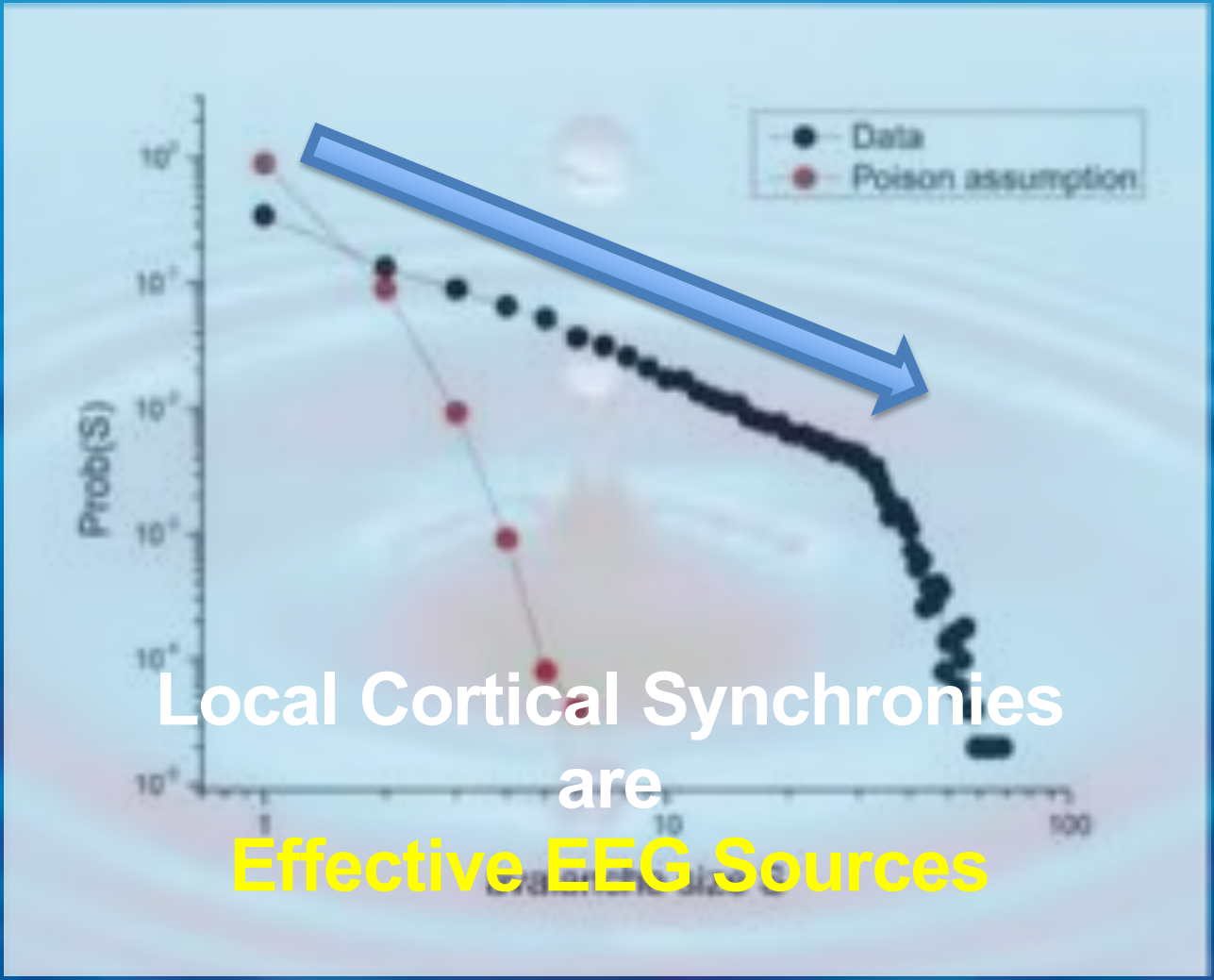


Jupiter, NASA

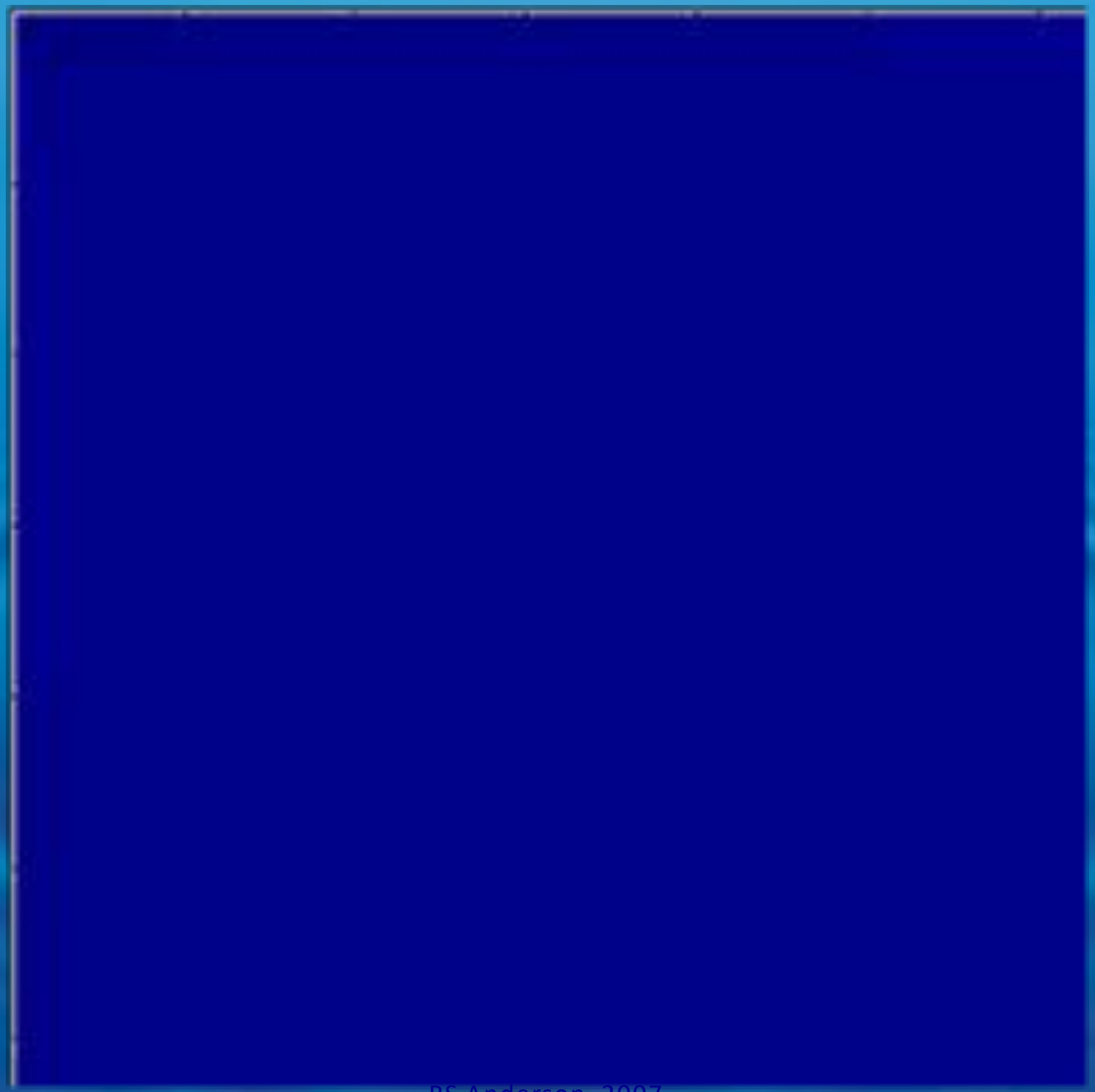
Phase cones (Freeman)

Avalanches (Plenz)

= Avalanches (Beggs & Plenz)



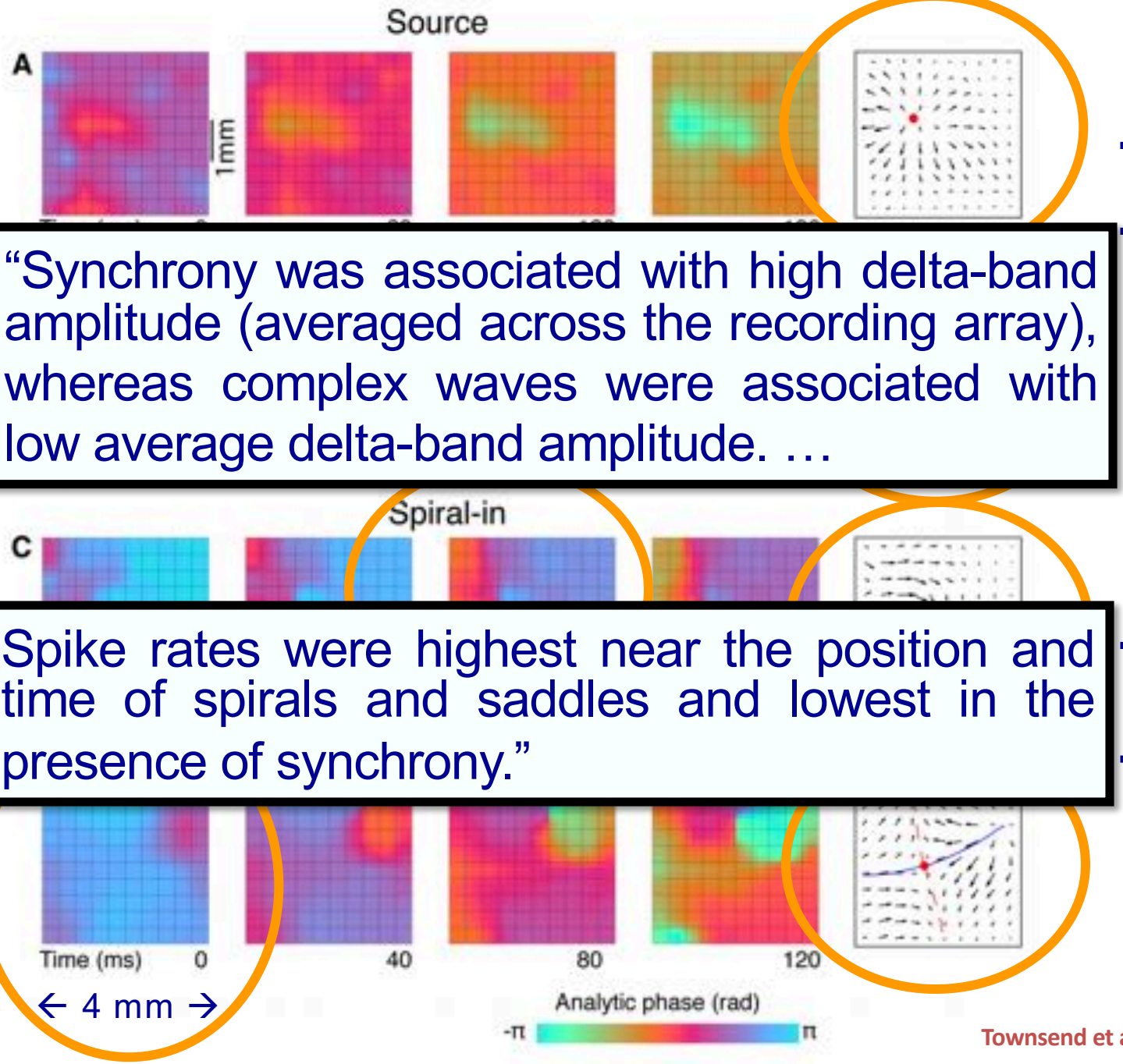
S. Makeig 2007



RS Anderson, 2007

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

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



Simple patterns

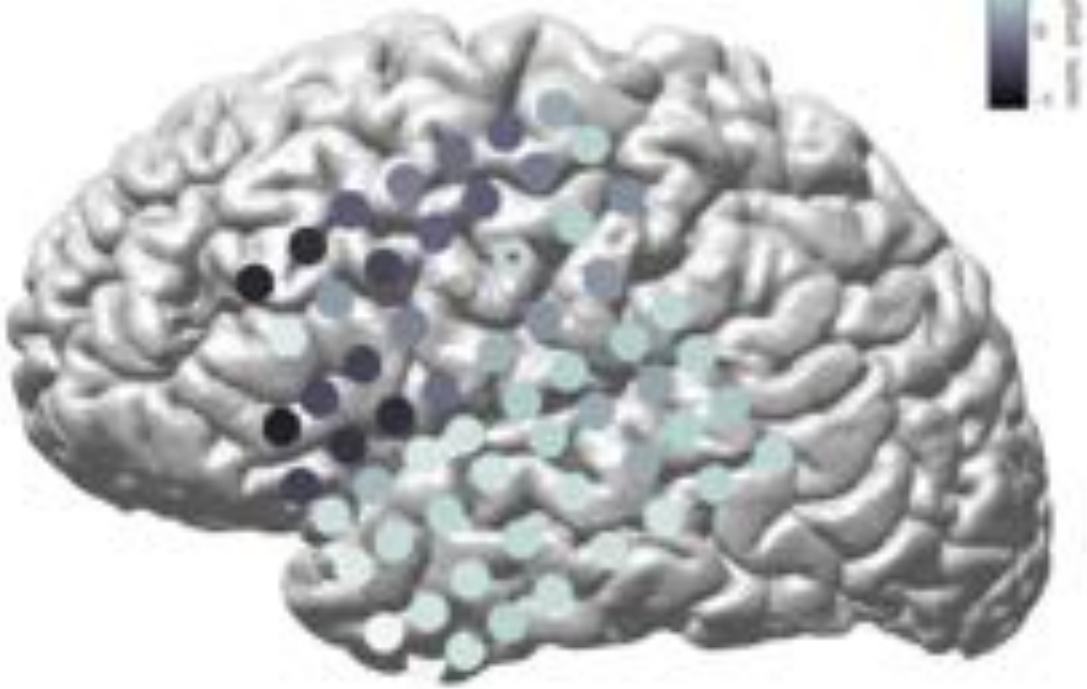
"Synchrony was associated with high delta-band amplitude (averaged across the recording array), whereas complex waves were associated with low average delta-band amplitude. …

Complex patterns

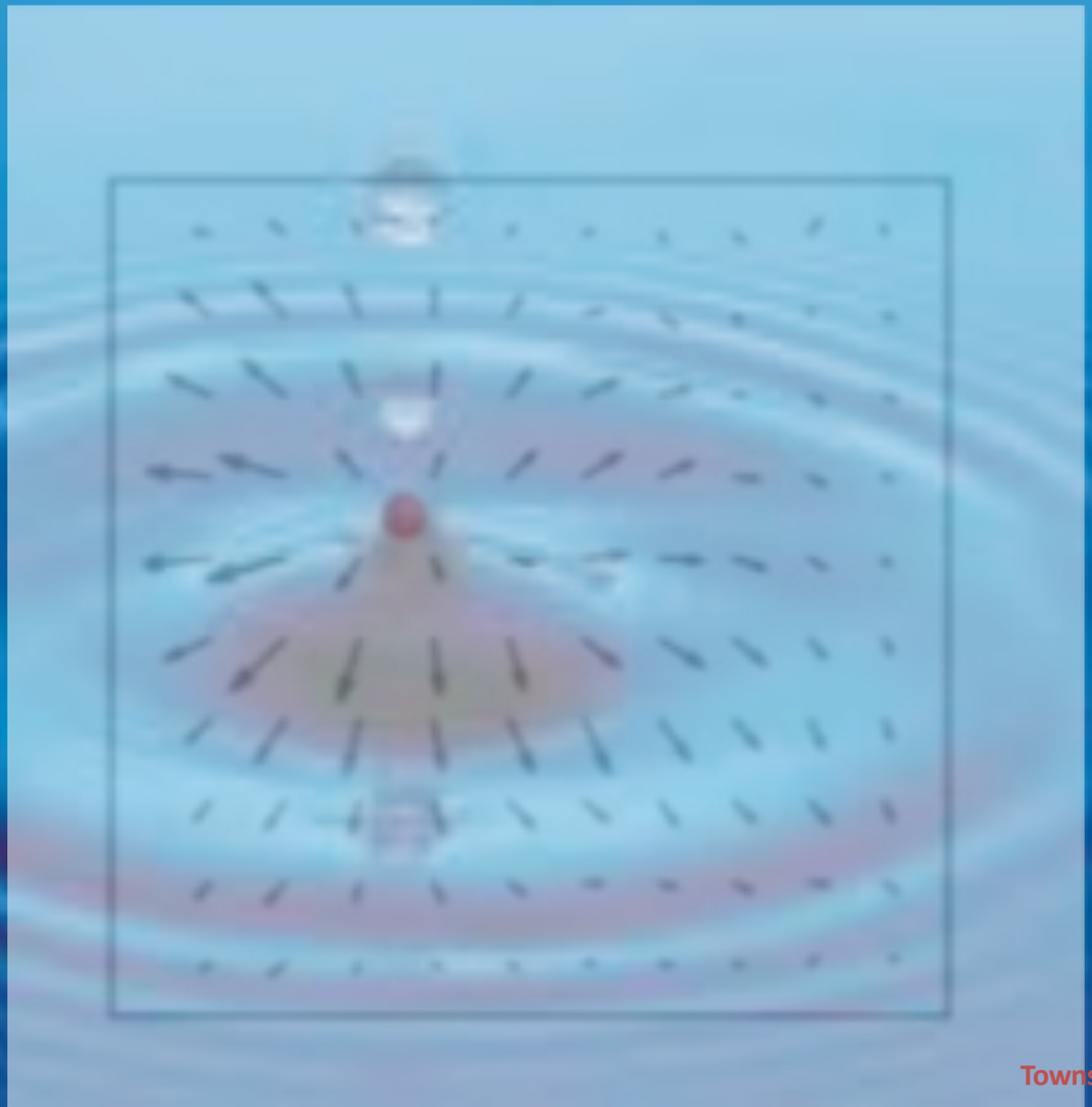
Spike rates were highest near the position and time of spirals and saddles and lowest in the presence of synchrony."

Townsend et al., 2015

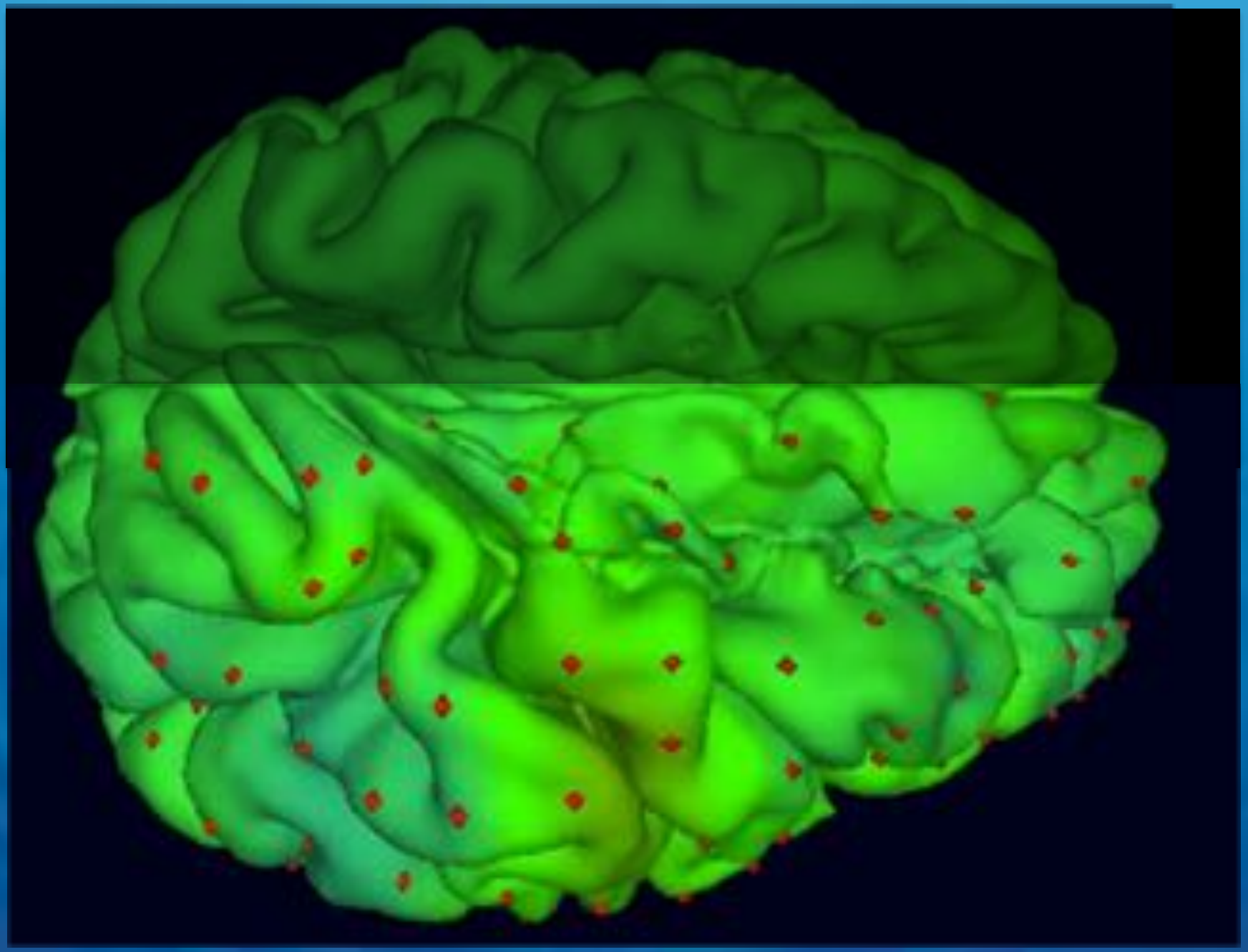
Sleep spindles



Muller et al., 2014



Townsend et al., 2015

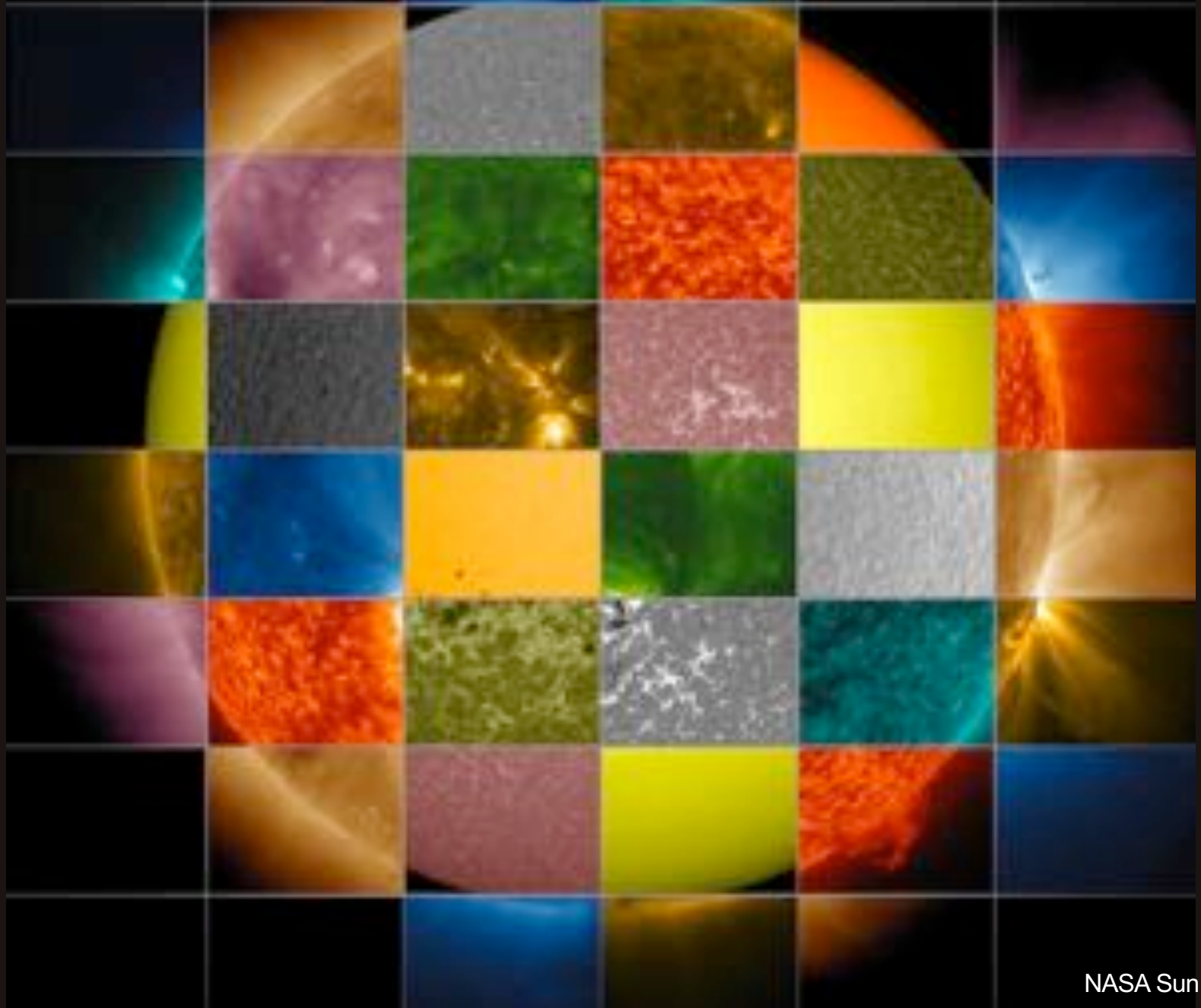


Z Akalin Acar, 2017

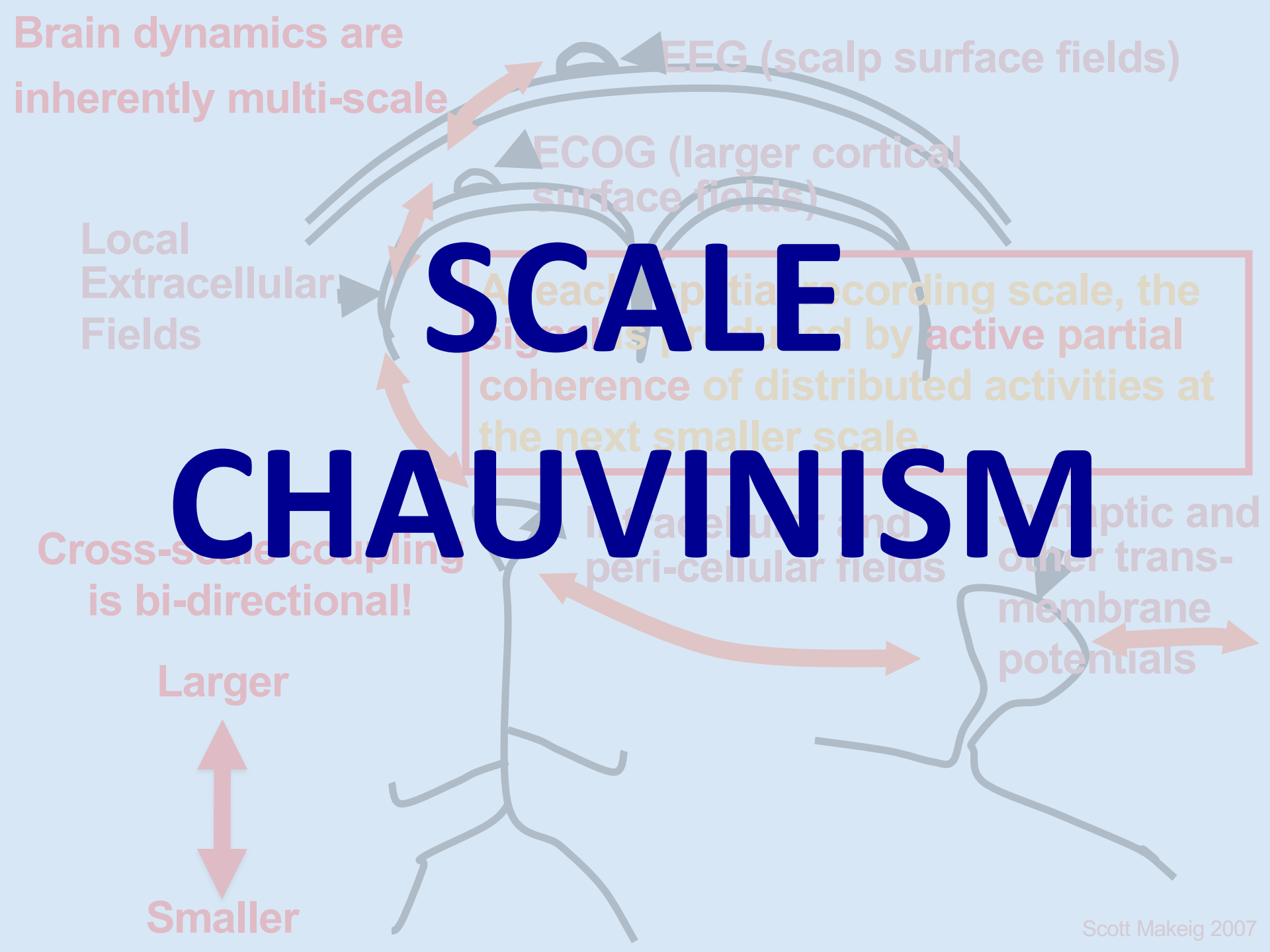
The spatiotemporal field dynamics of cortex and brain have not yet been imaged on multiple spatial scales!

Alan Friedman

Spatial complexity involves frequency



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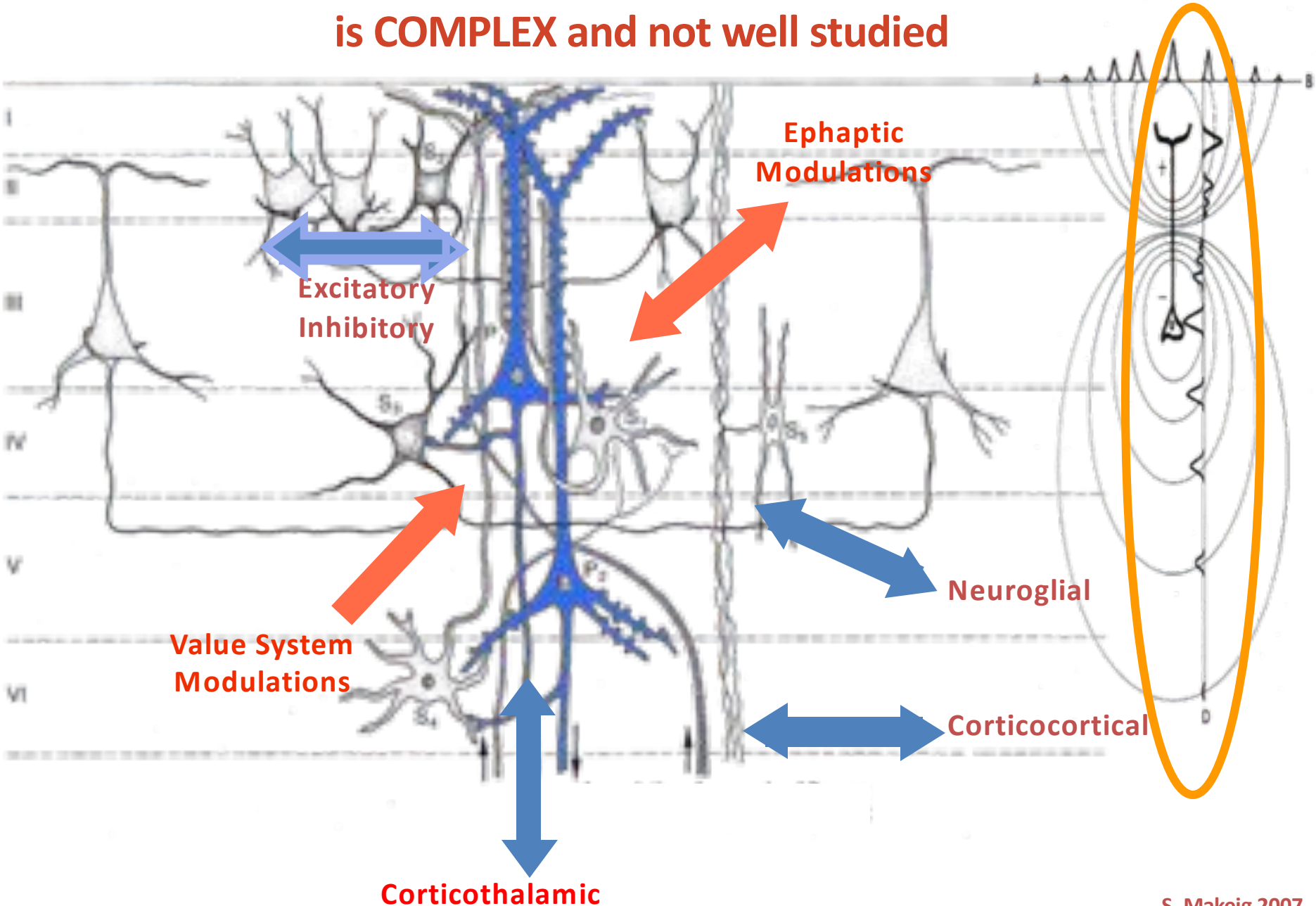
EEG (scalp surface fields)
ECOG (larger cortical surface fields)
Local Extracellular Fields
At each spatial recording scale, the signals produced by active partial coherence of distributed activities at the next smaller scale
SCALE CHAUVINISM
Cross-scale coupling is bi-directional!
Intracellular and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

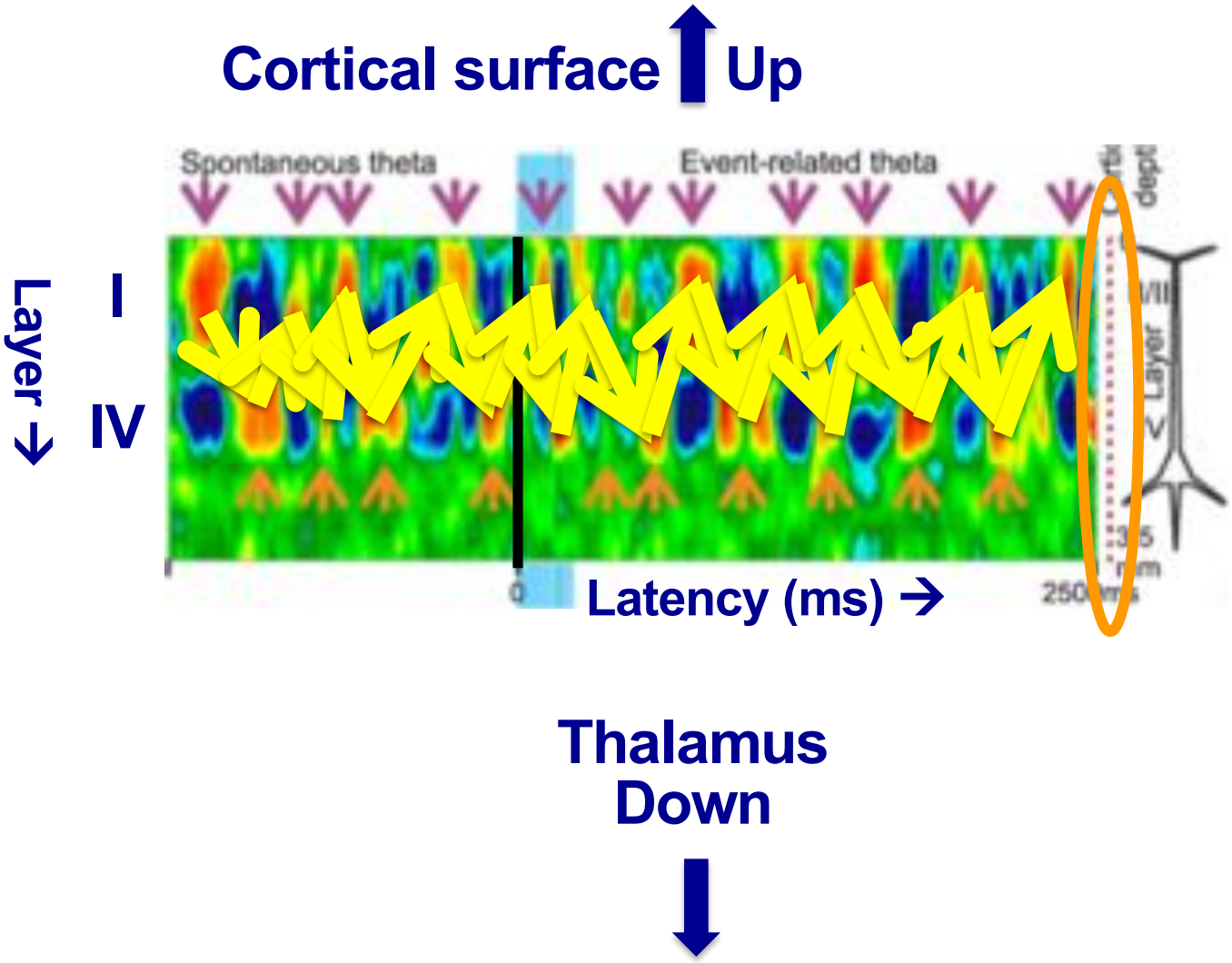
The generation and modulation of EEG is COMPLEX and not well studied

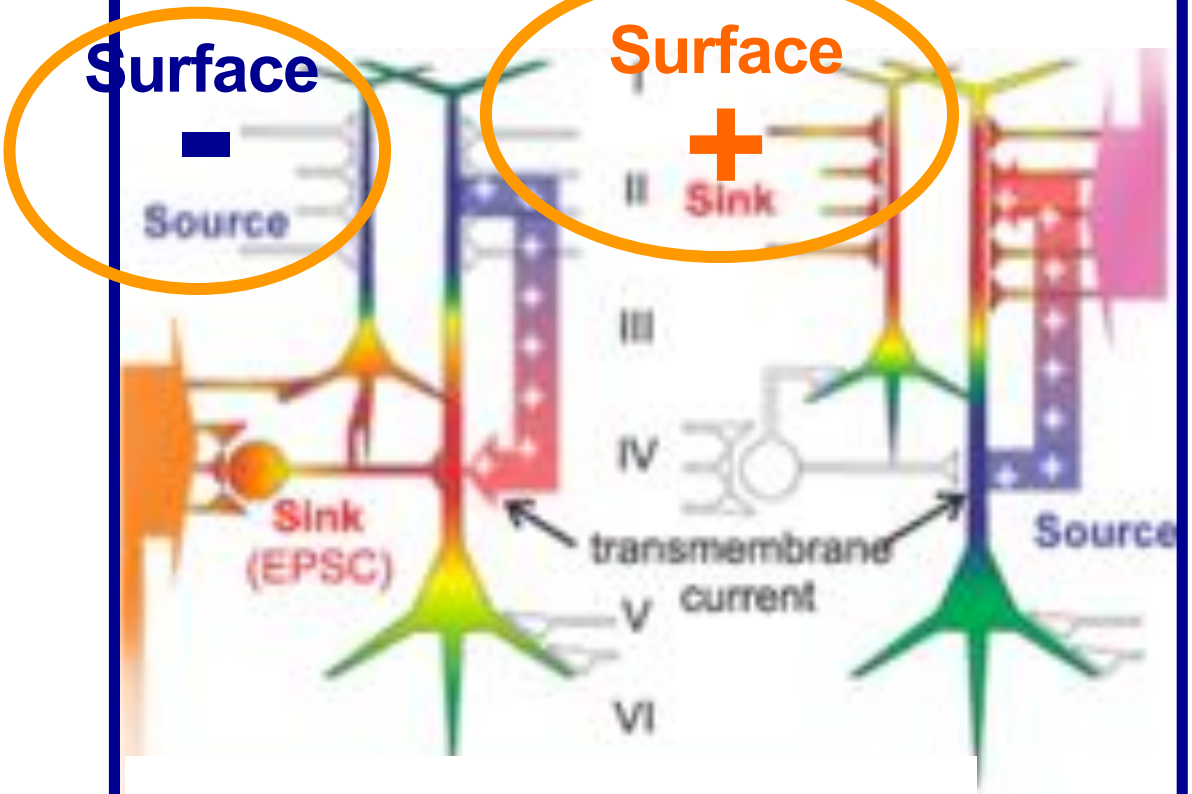


S. Makeig 2007

In Cortex: Up ≠ Down

(and +μV ≠ -μV)



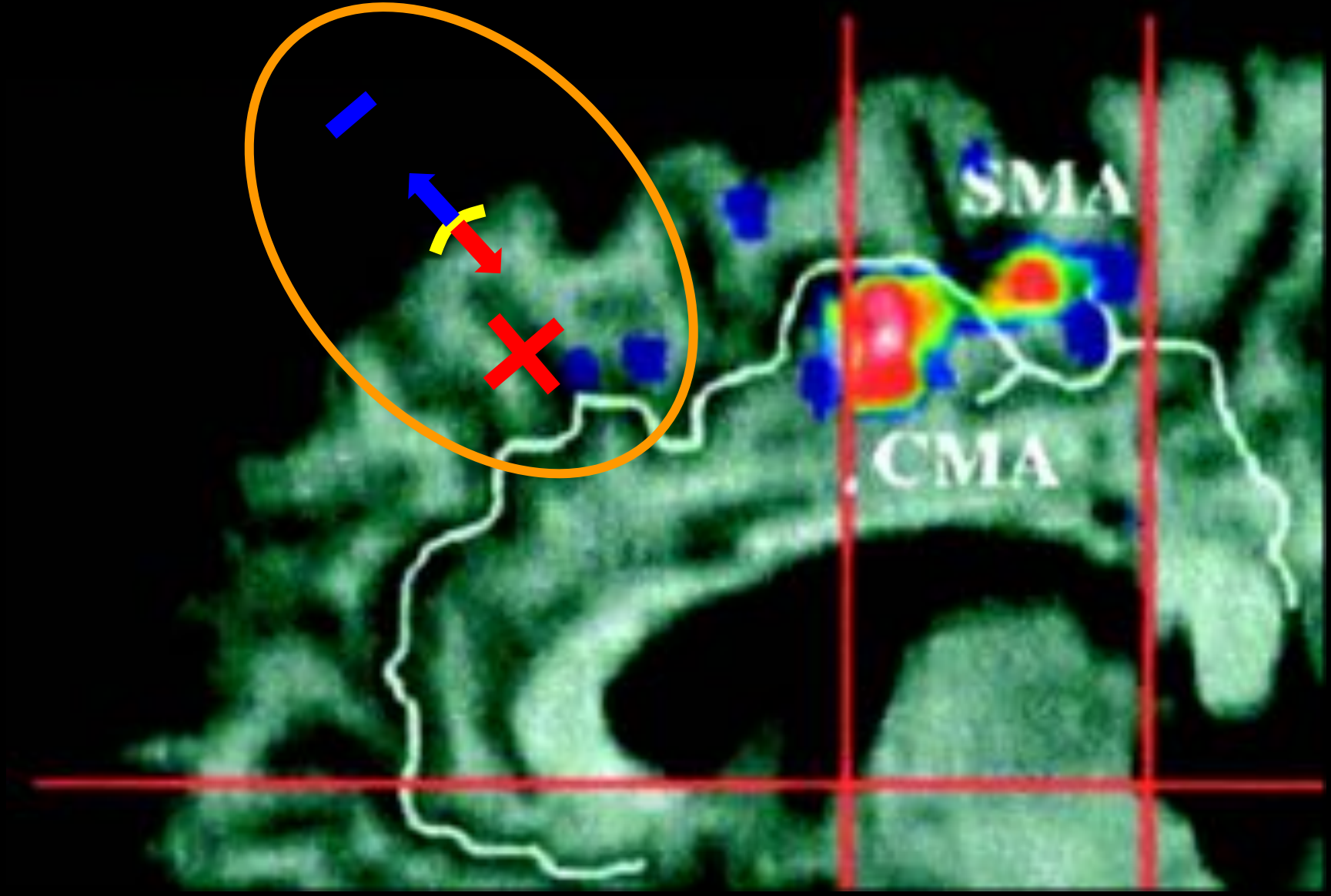


From E. Halgren et al., 2015

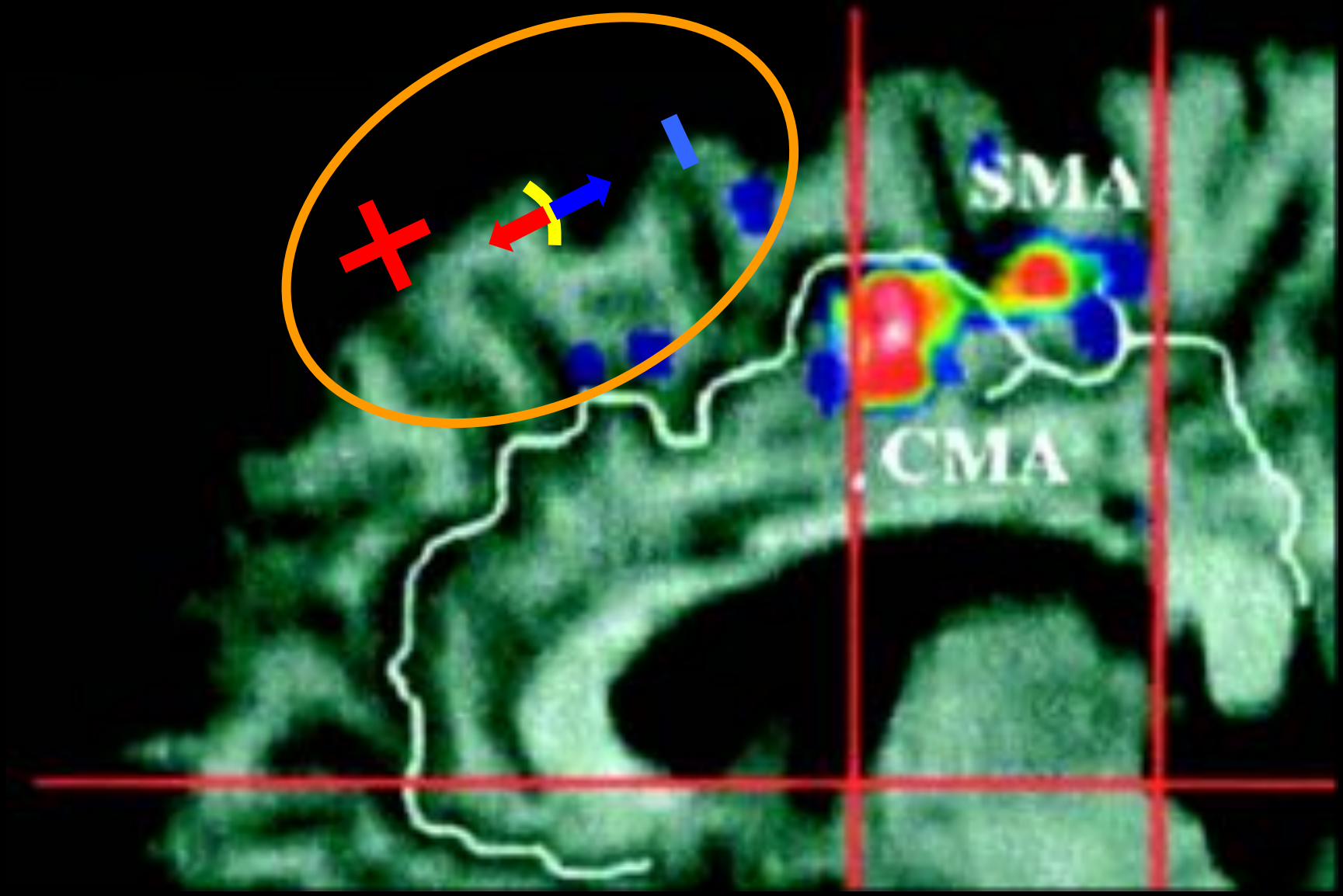
(see T. Elbert, ~1990)

Slide: S. Makeig, 2016

Cortical Up ≠ Towards the Scalp

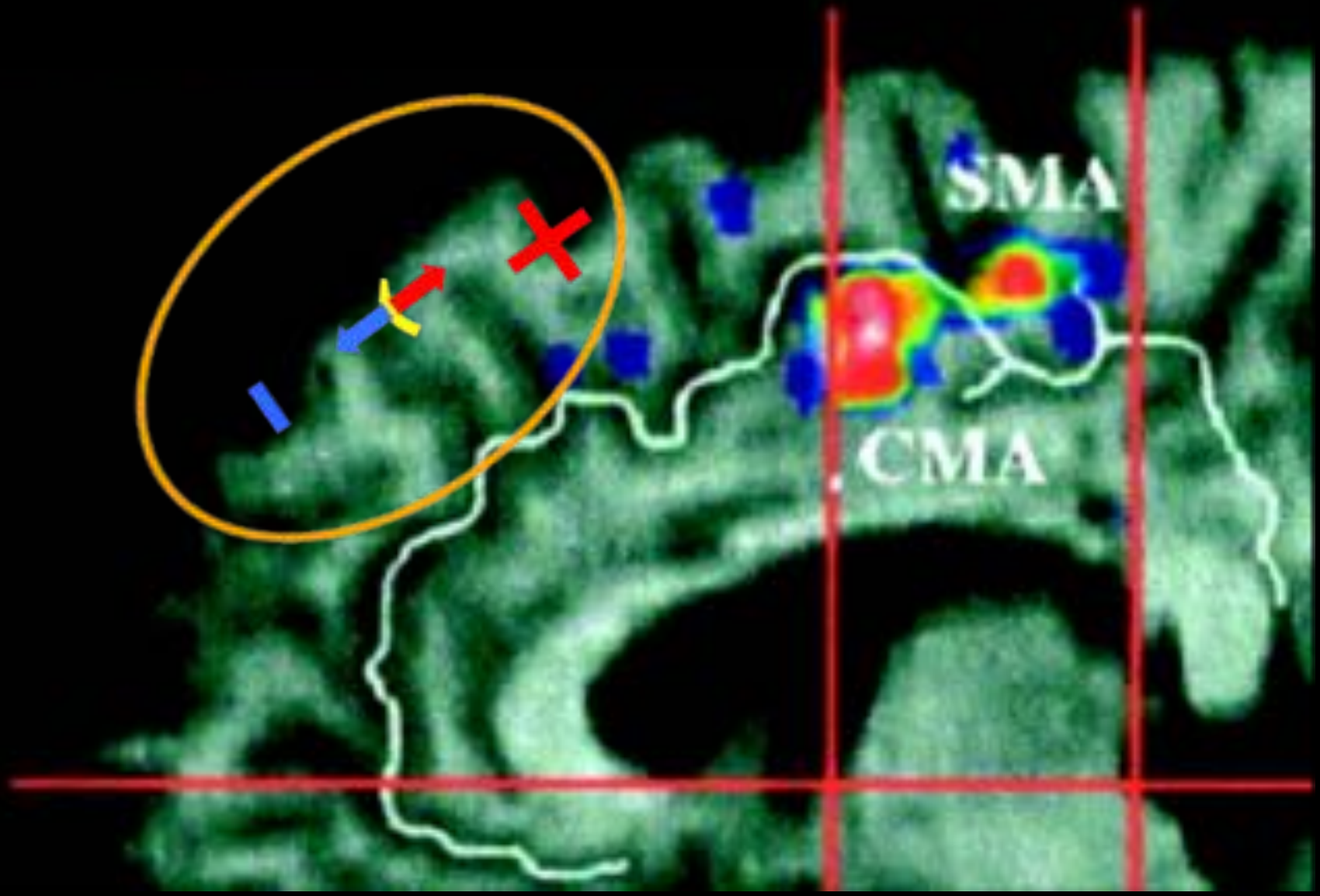


Cortical Up ≠ Towards the Scalp



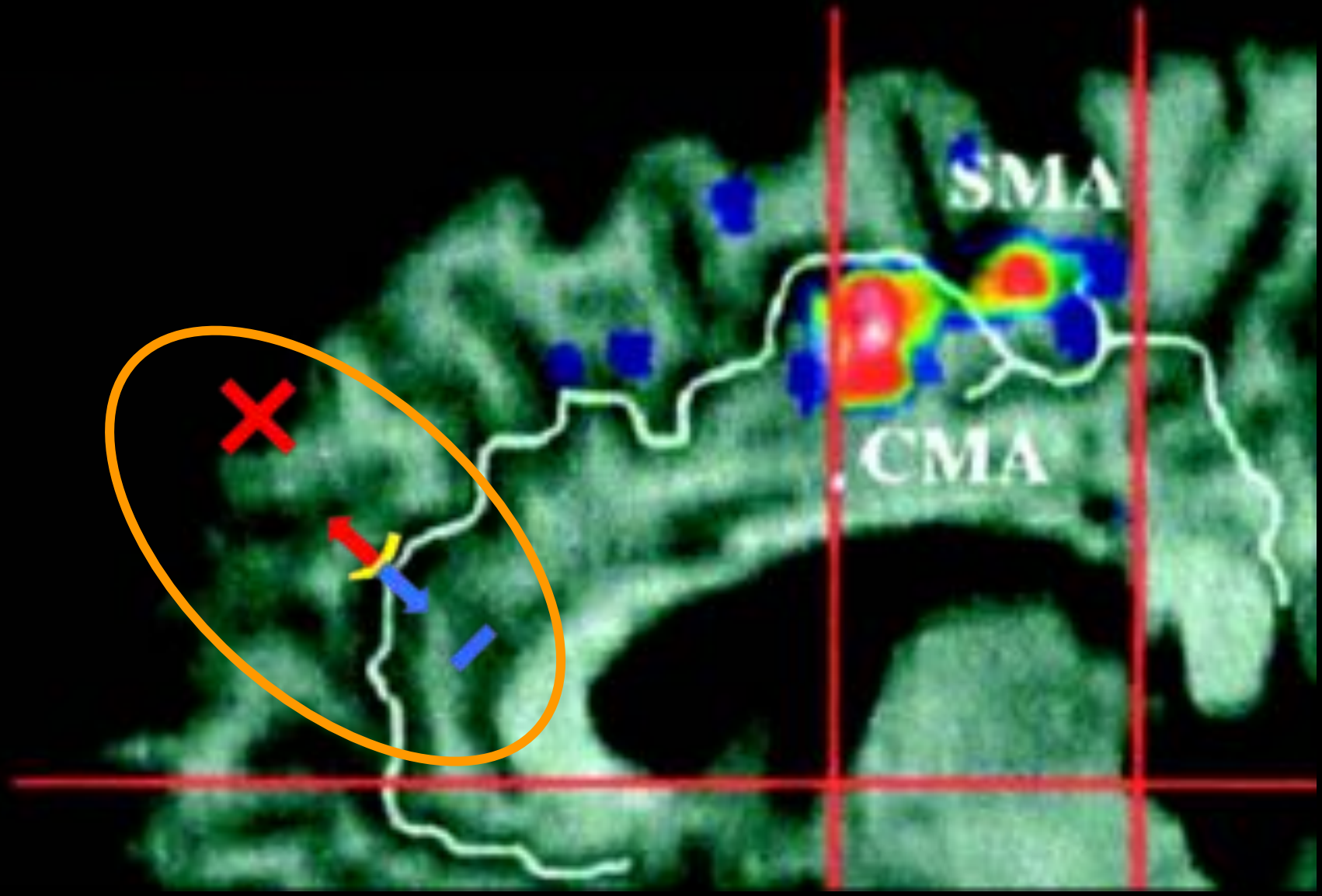
Slide: S. Makeig, 2017

Cortical Up ≠ Towards the Scalp



Slide: S. Makeig, 2017

Cortical Up ≠ Towards the Scalp



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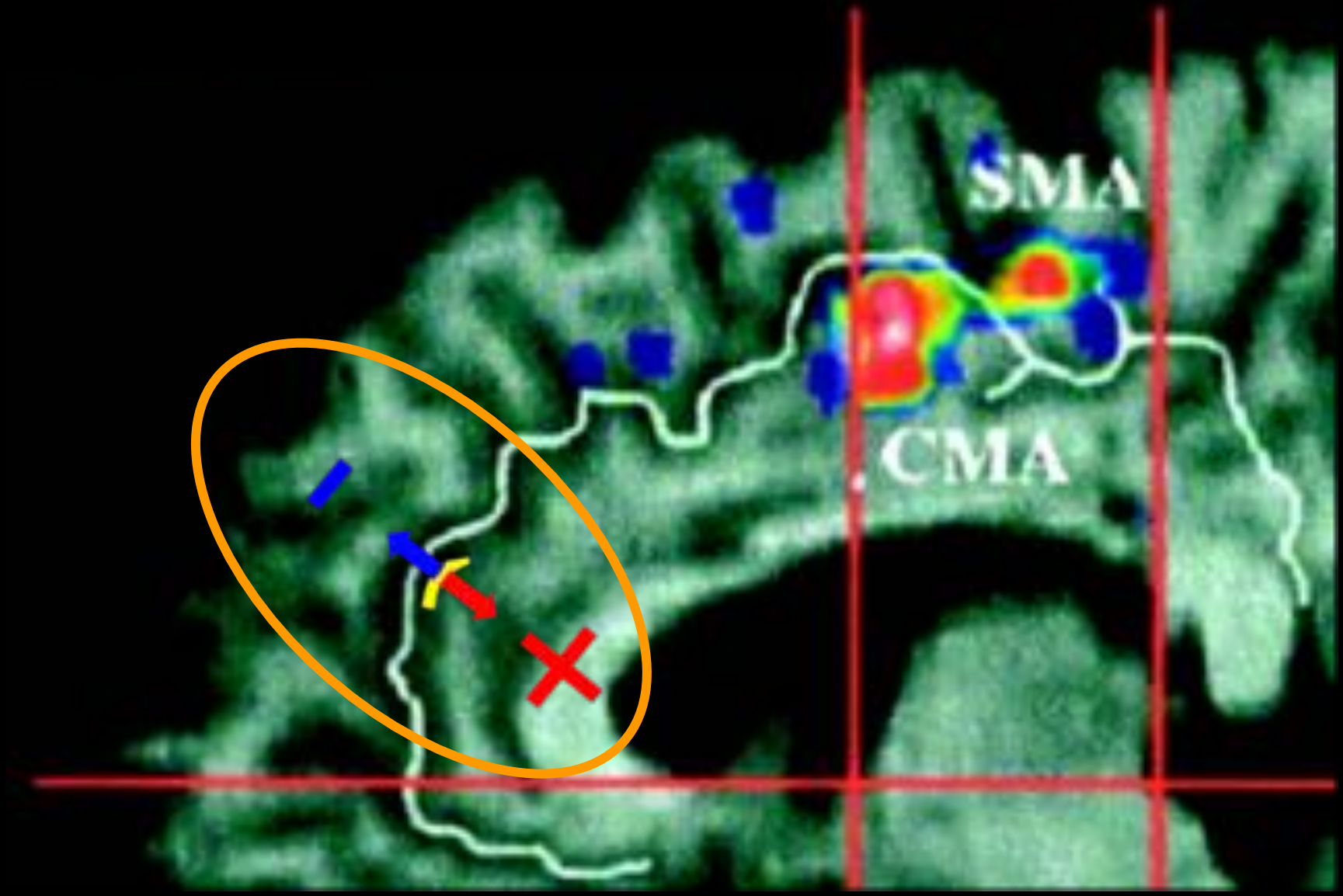
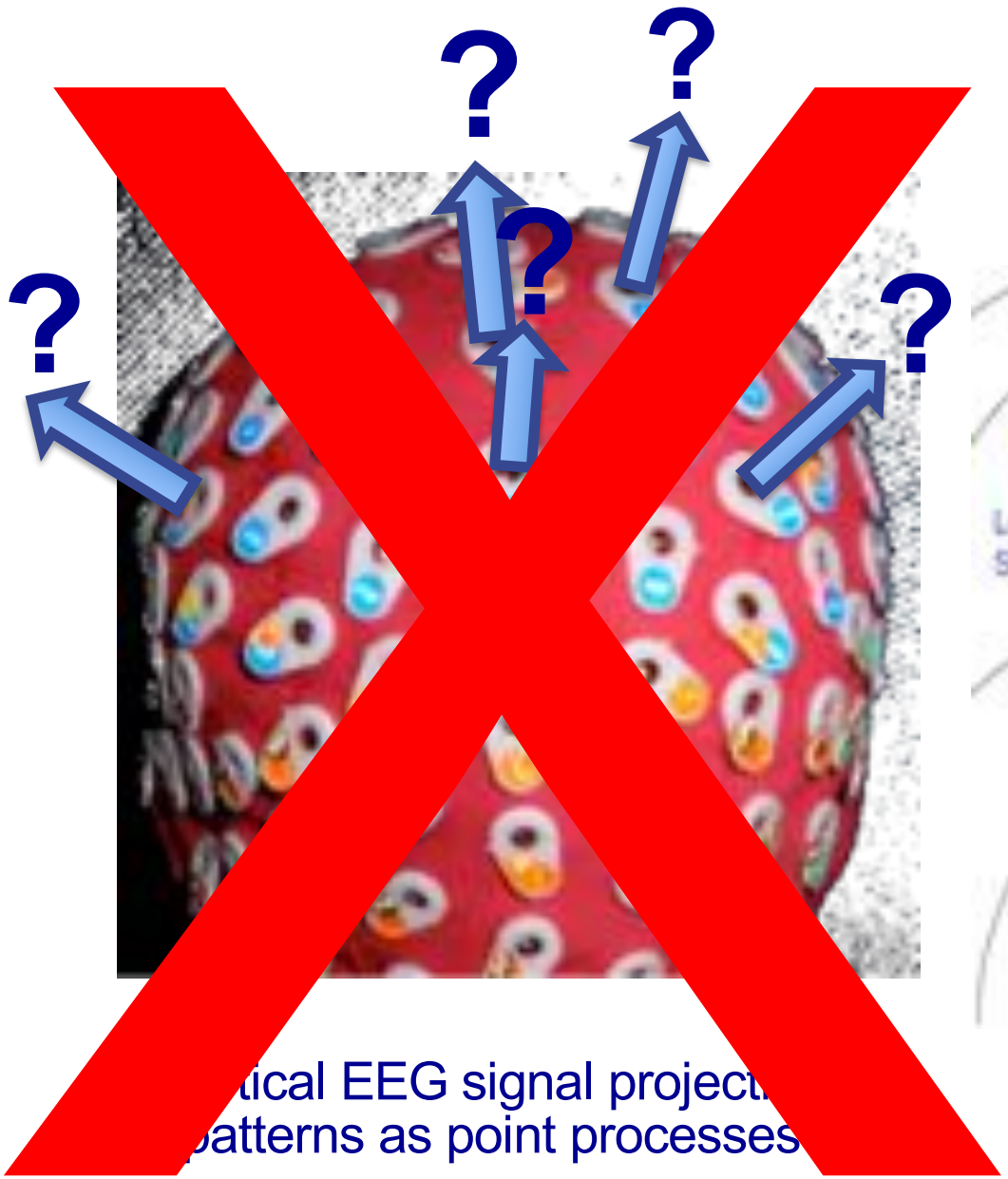
Cortical Up ≠ Towards the Scalp

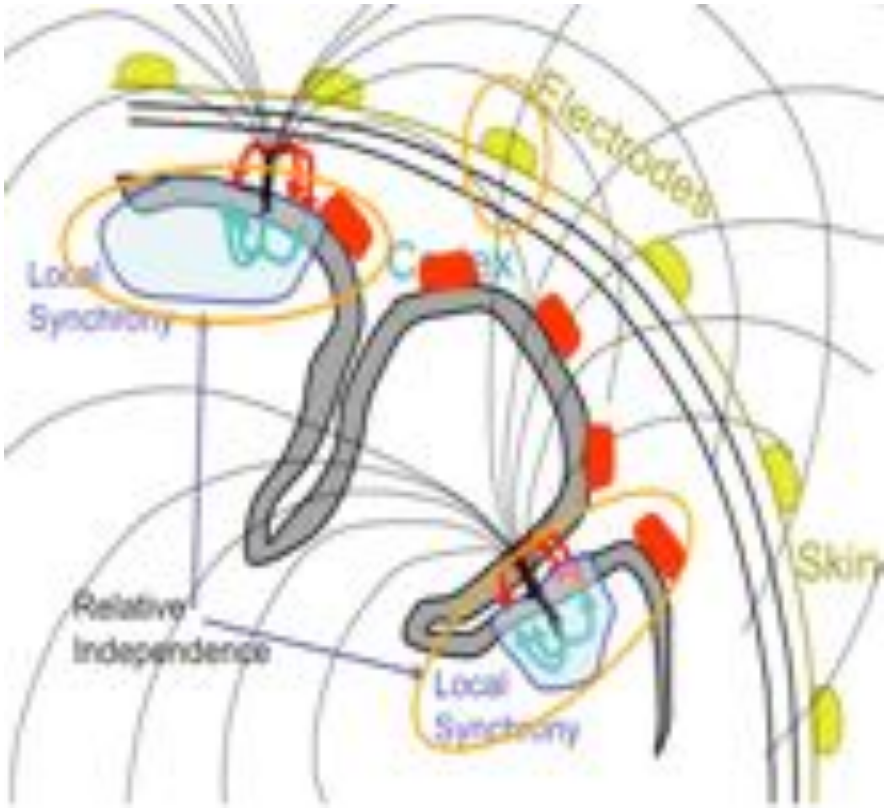


Slide: S. Makeig, 2017

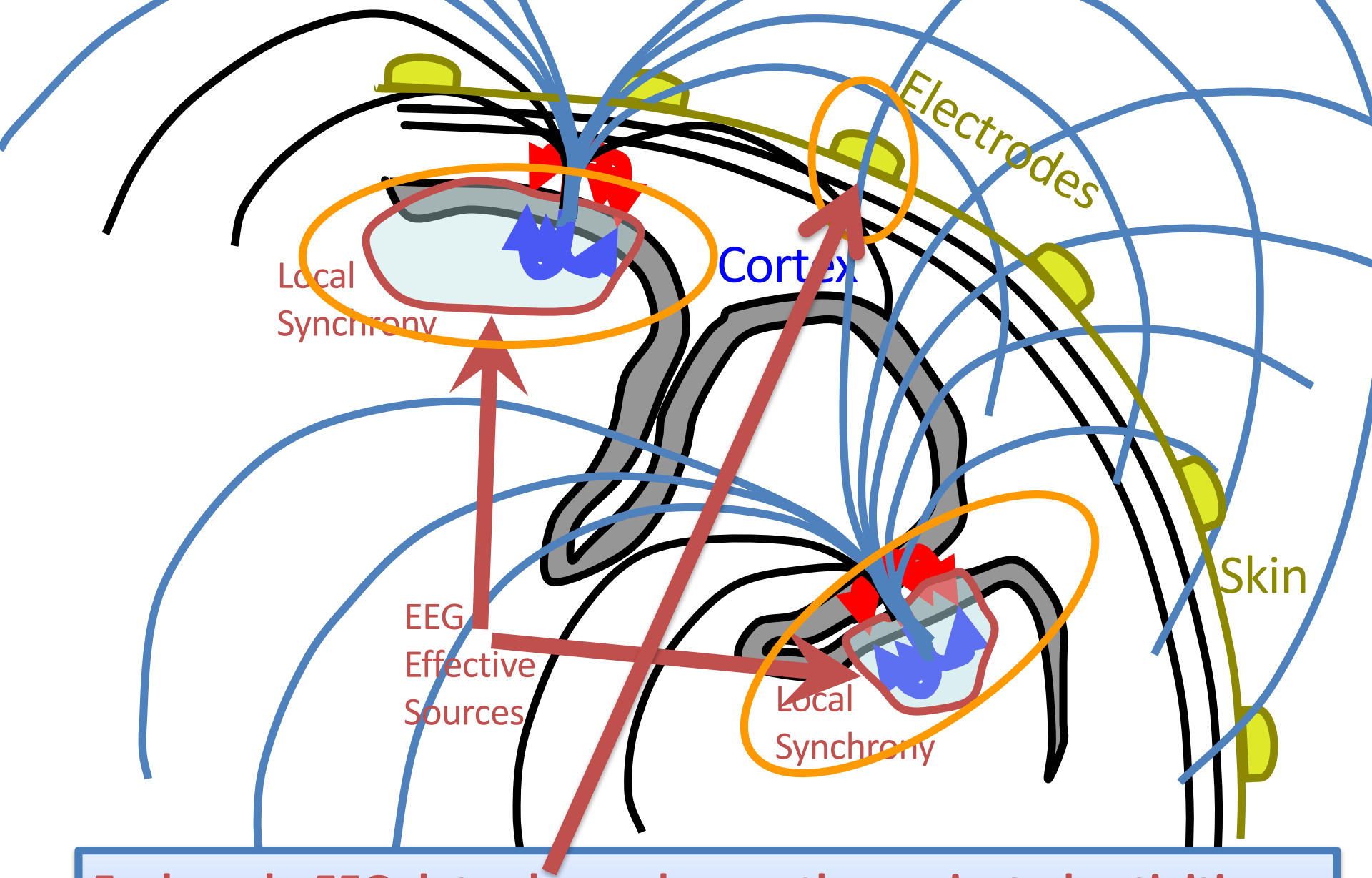
Naïve 2-D interpretation of EEG signals?



tical EEG signal projecti
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