Mining Cognitive Brain Dynamics I

Scott Makeig

Institute for Neural Computation

University of California San Diego

13th EEGLAB Workshop @ Aspet, France

June, 2011

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 …

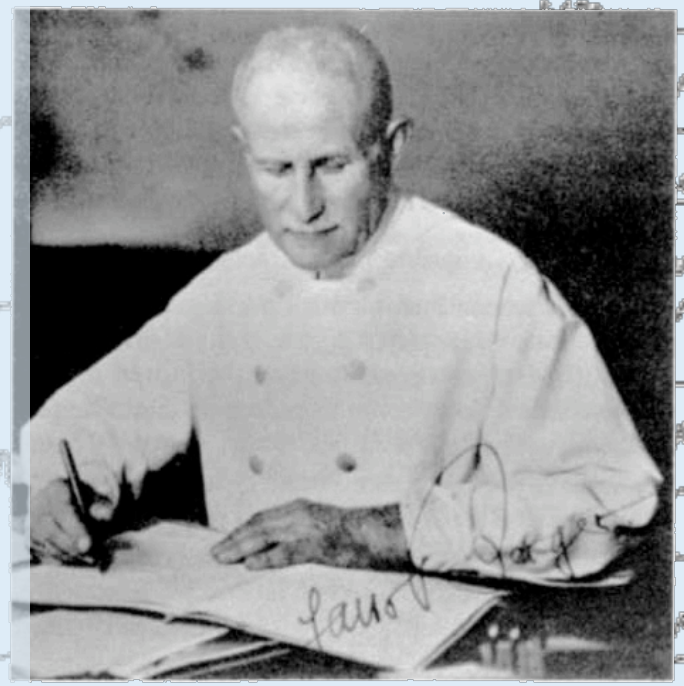


FIGURE 1–1.—Professor Hans Berger (1873–1941), neuropsychiatrist, University of Jena, Jena, Germany, first to discover and describe in 1929 a unique kind of electrical activity recorded from the brain of man, which he named the electroencephalogram (Elektrenkephalogramm).

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

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, 2004) 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 - Experimental Real-time Interactive Control & Analysis, SIFT, BCILAB, etc.**
- 2010 – Workshops in Jyvaskyla Finland, NCTU, Taiwan, Portland Oregon, and UCSD
- **2011 - 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	@petridish.edu	EEG and ERP responses to music stimuli
US EDU	@wjh.harvard.edu	Neuroscience
US EDU	@wlu.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

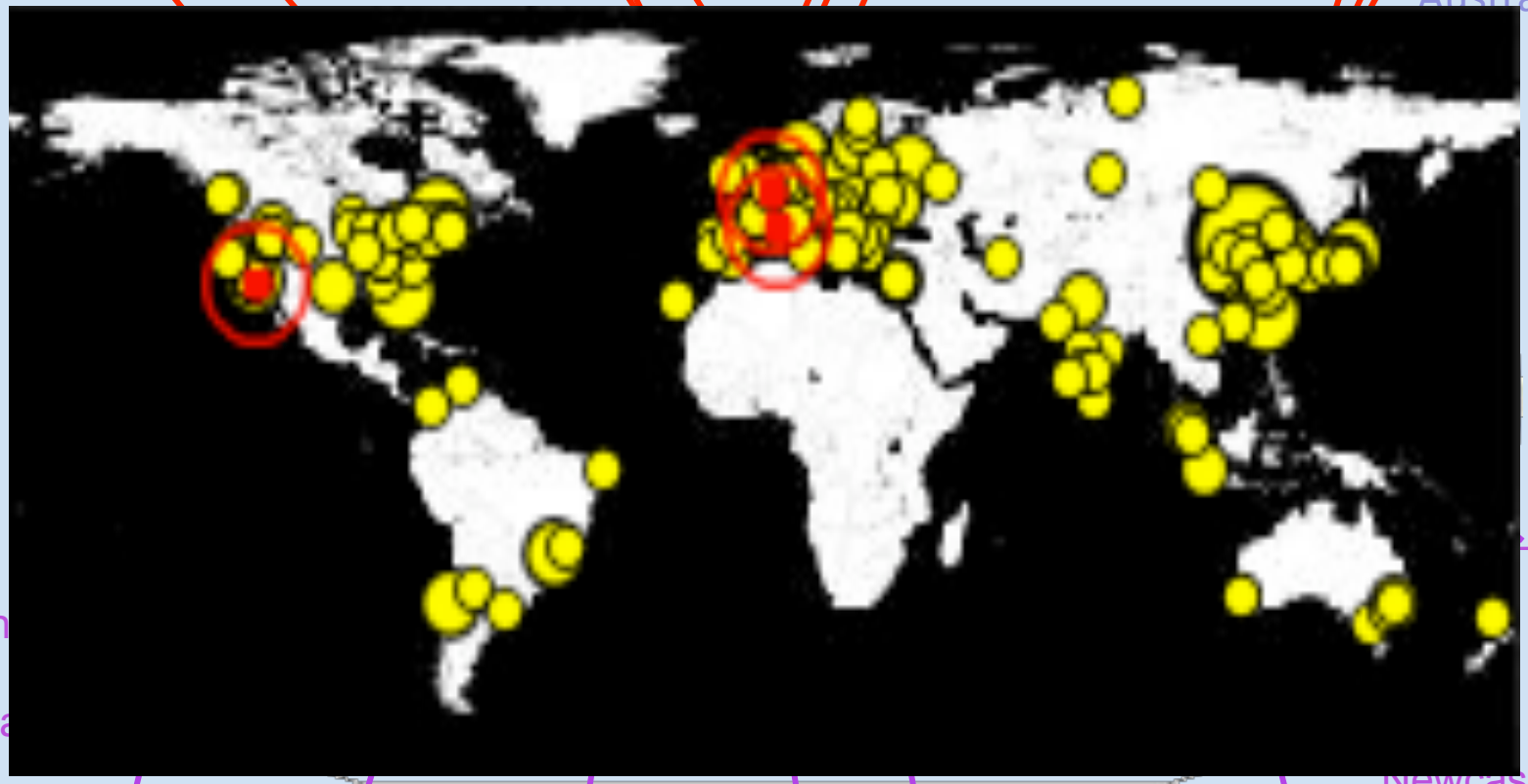
- > 3,500 on the 'eeglablist' discussion list
- 30+ EEGLAB plug-ins available

S. Makeig 2007

EEGLAB Workshops

90 Participants:

- Canada
- USA
- Norway
- Ireland
- England
- Germany
- Austria
- Italy
- Japan
- Taiwan
- S. Korea
- Australia



Bloomin

Portla

Taiwan

La Jolla

Santiago

Porto

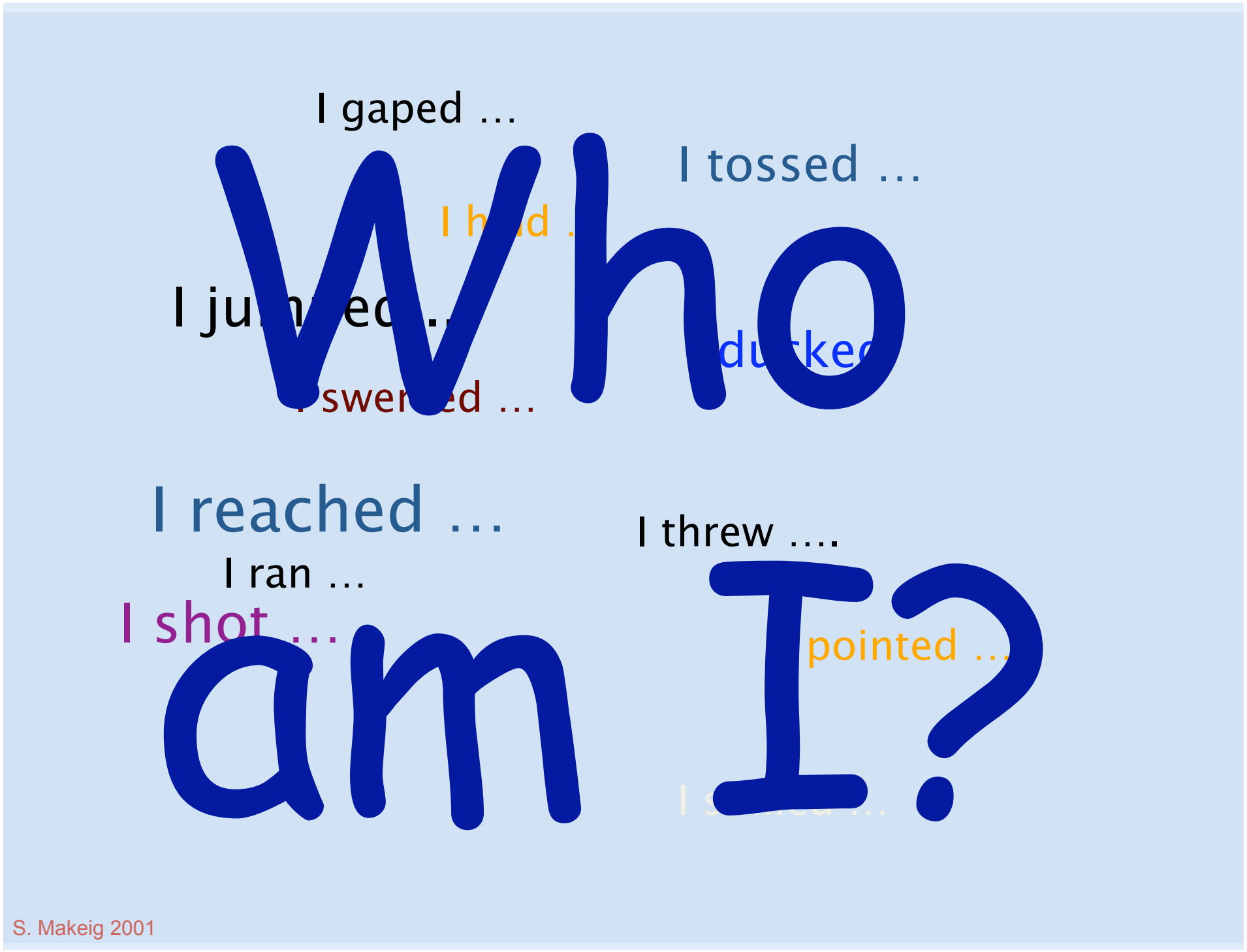
Aspet

Jyväskylä

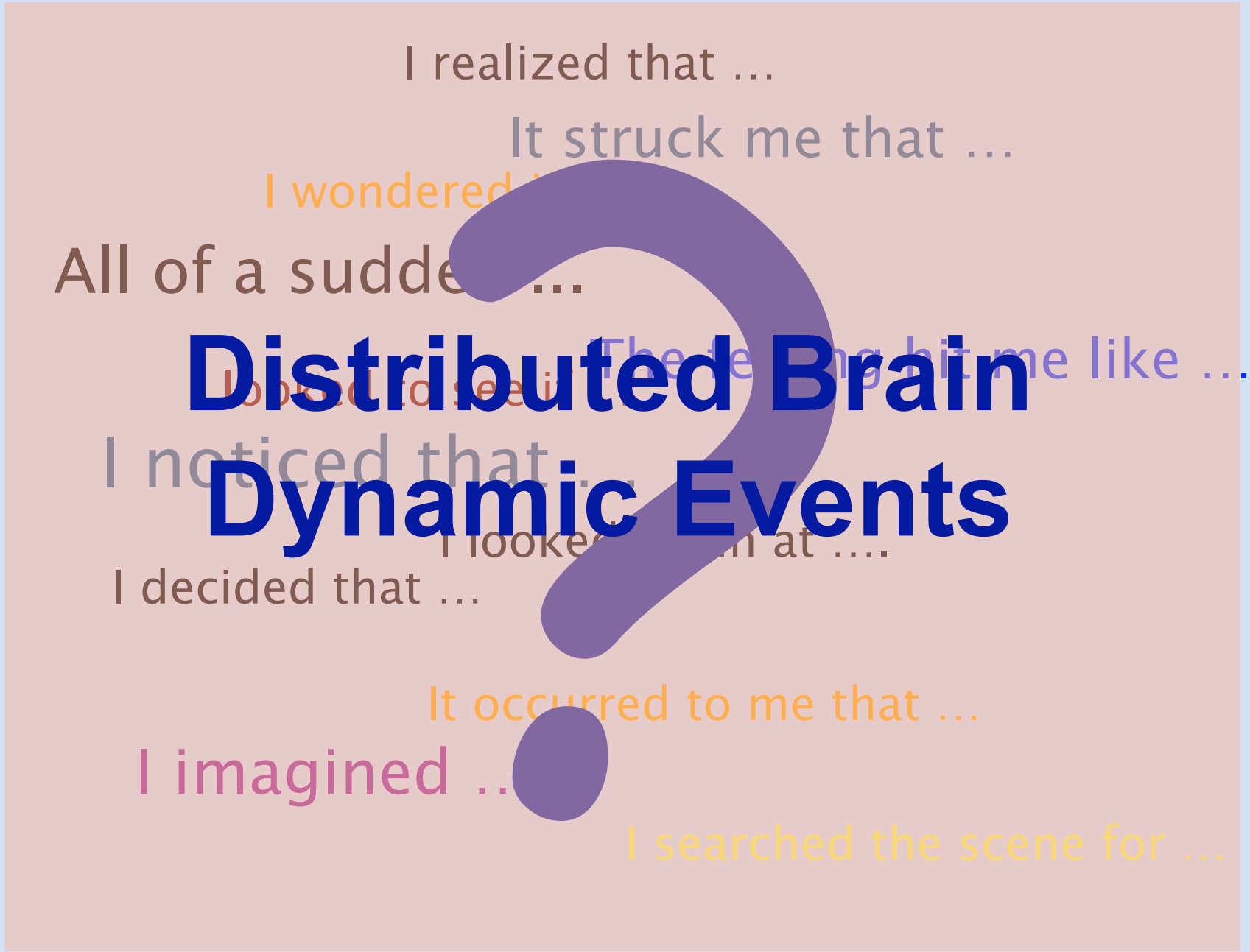
Singapore

Newcastle

S. Makeig 2010

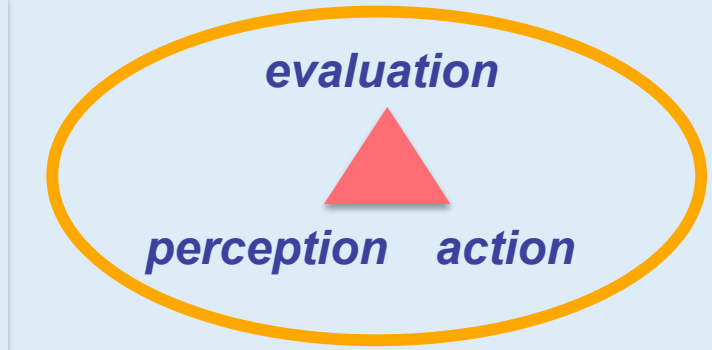


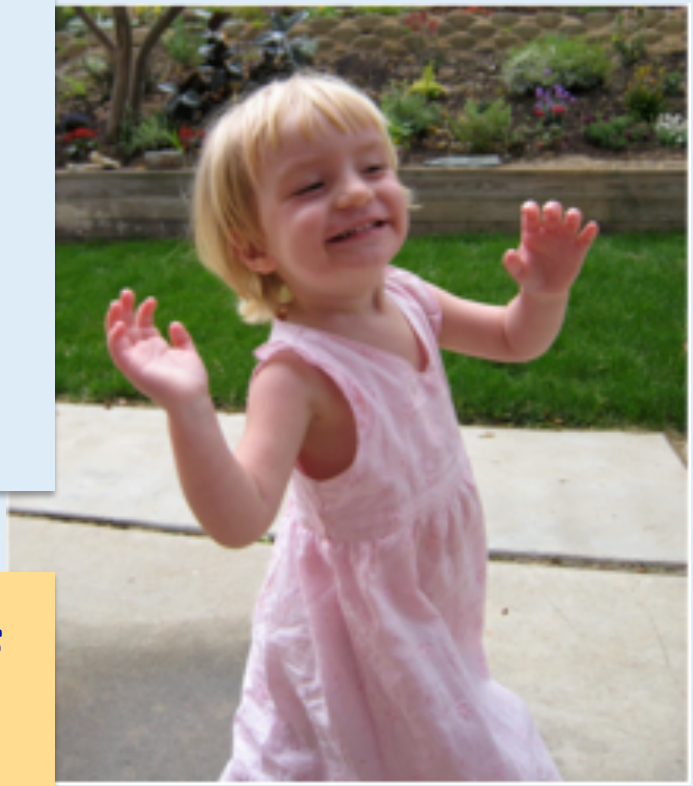
S. Makeig 2001


I realized that …
It struck me that …
I wondered
All of a sudde …
I noticed that …
I decided that …
It occurred to me that …
I imagined …
I searched the scene for …
Distributed Brain
Dynamic Events

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.

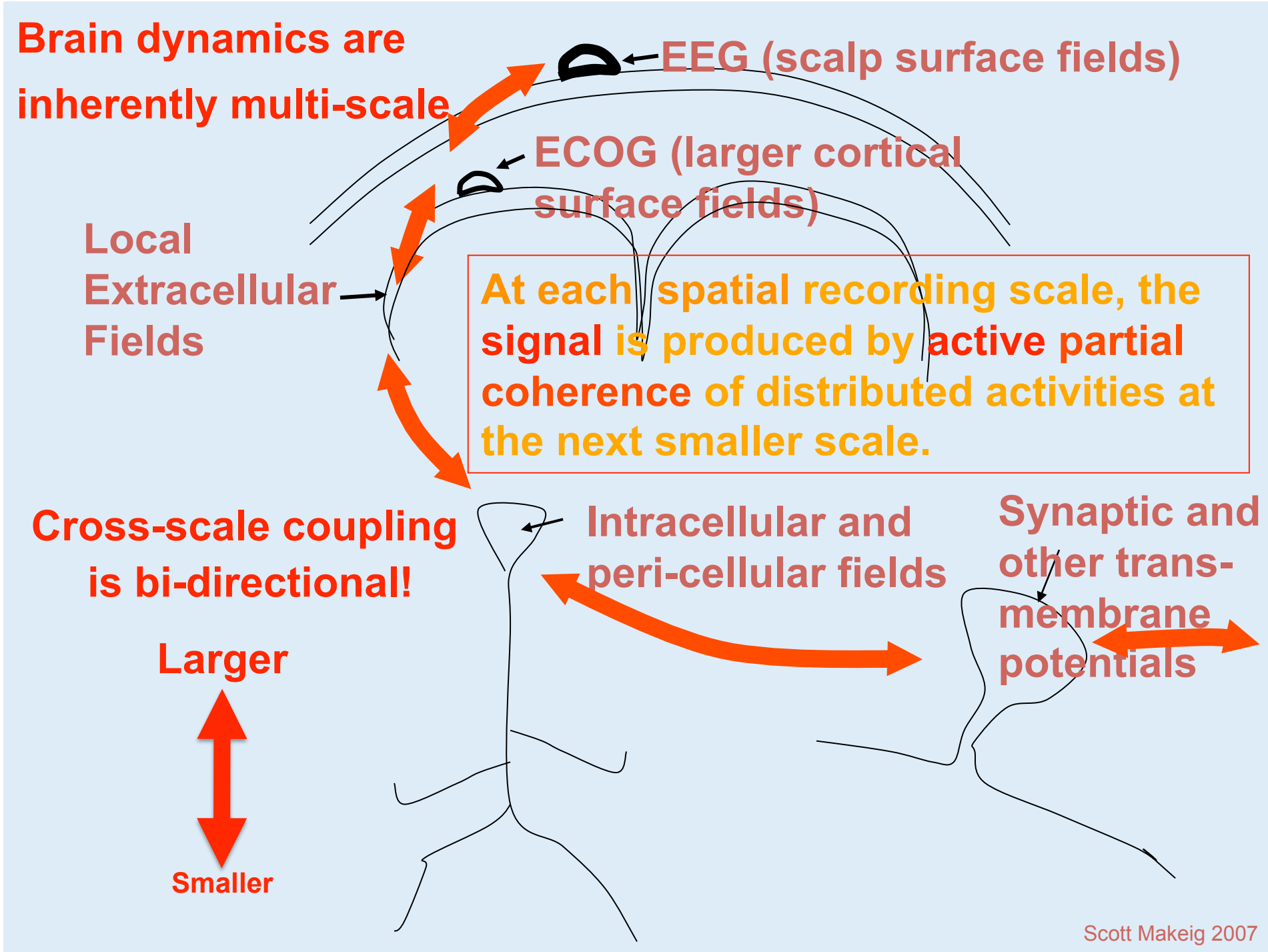




Brains meet the challenge of the moment!

What is EEG?

Makeig (2006)

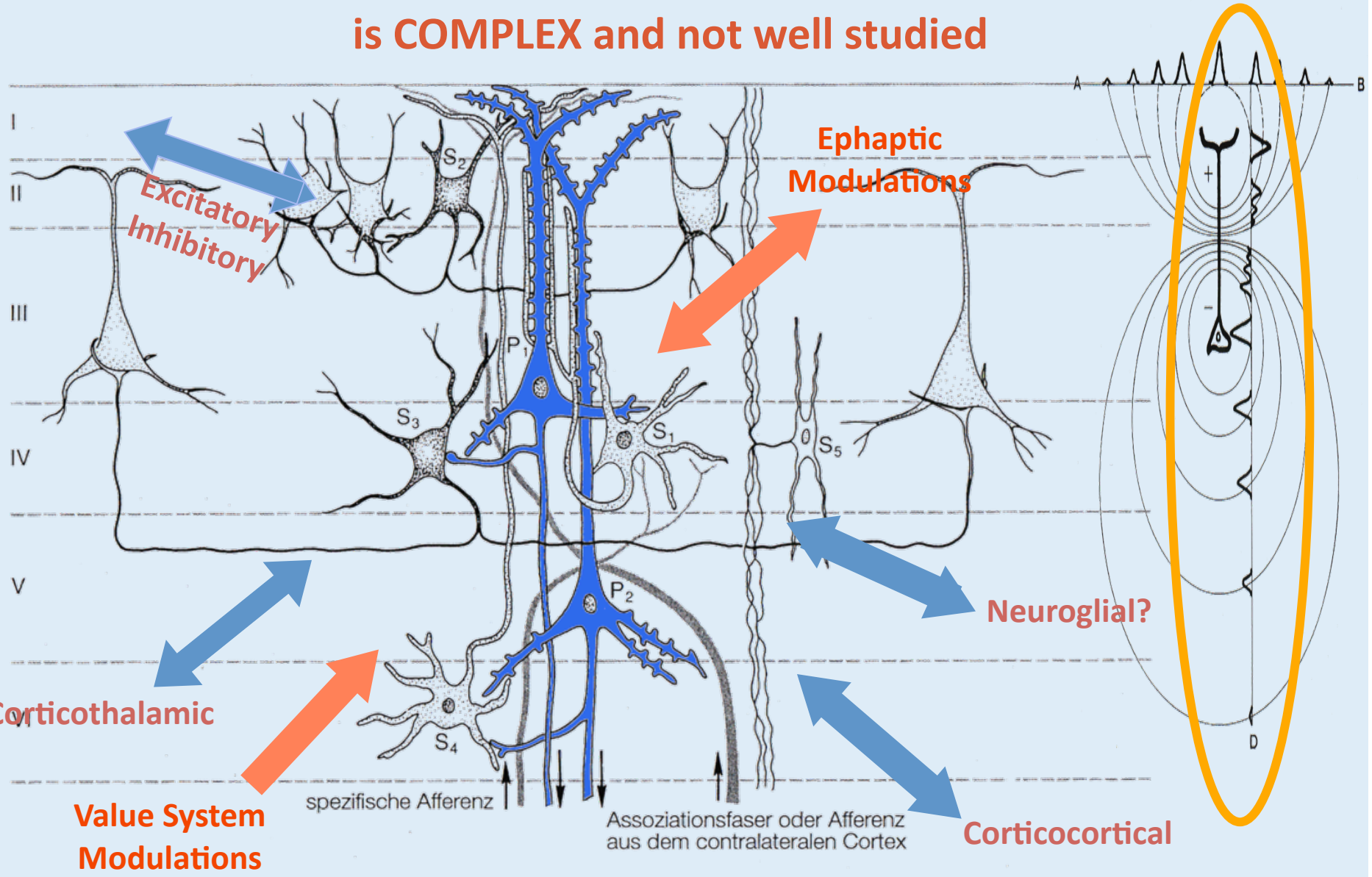

Brain dynamics are inherently multi-scale
EEG (scalp surface fields)
ECOG (larger cortical surface fields)
Local Extracellular Fields
At each spatial recording scale, the signal is produced by active partial coherence of distributed activities at the next smaller scale.
Cross-scale coupling is bi-directional!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

SCALE CHAUVINISM

Brain dynamics are inherently multi-scale

Scott Makeig 2007

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



S. Makeig 2007

Functional Brain Imaging

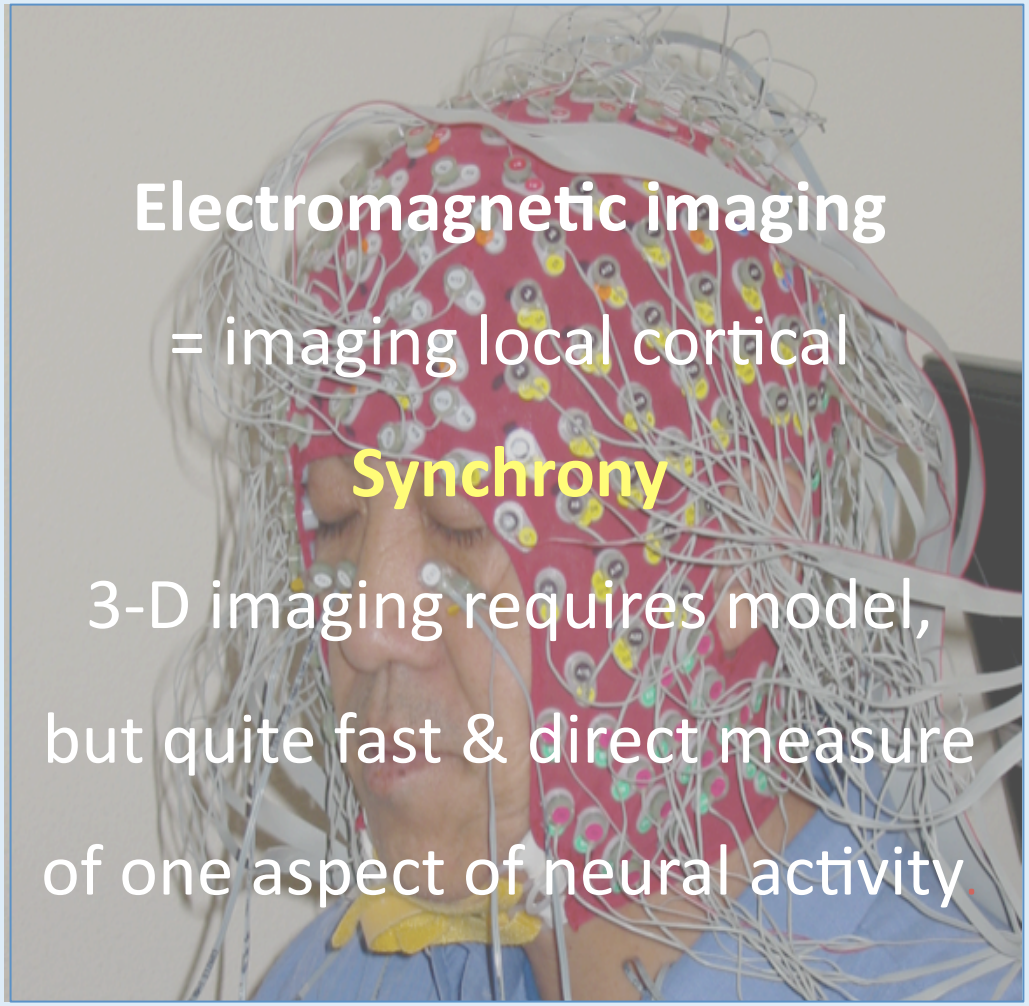
Hemodynamic imaging

= imaging brain

Energy

Direct 3-D inverse model,

but quite slow & indirect



Electromagnetic imaging

= imaging local cortical

Synchrony

3-D imaging requires model,

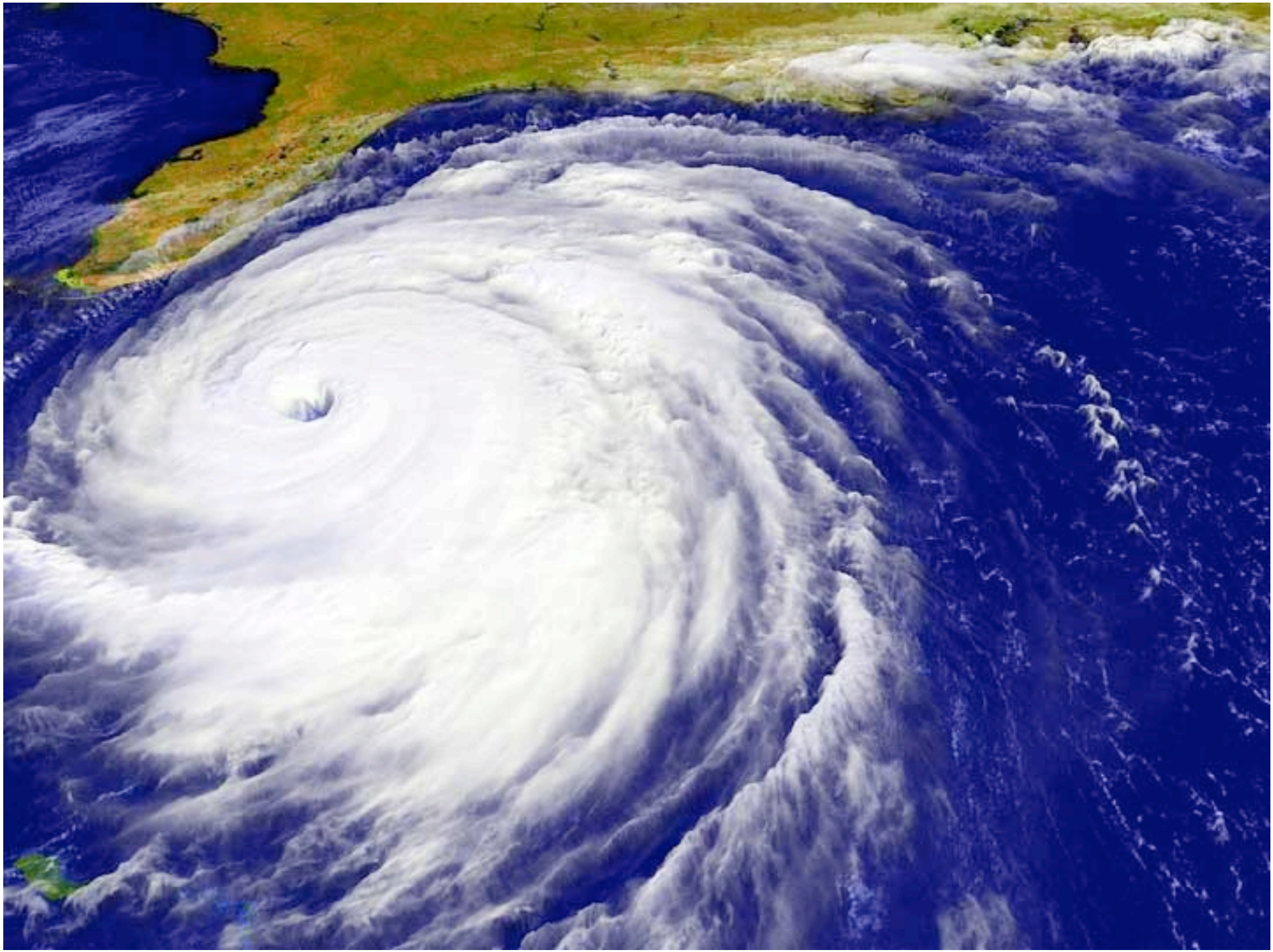
but quite fast & direct measure

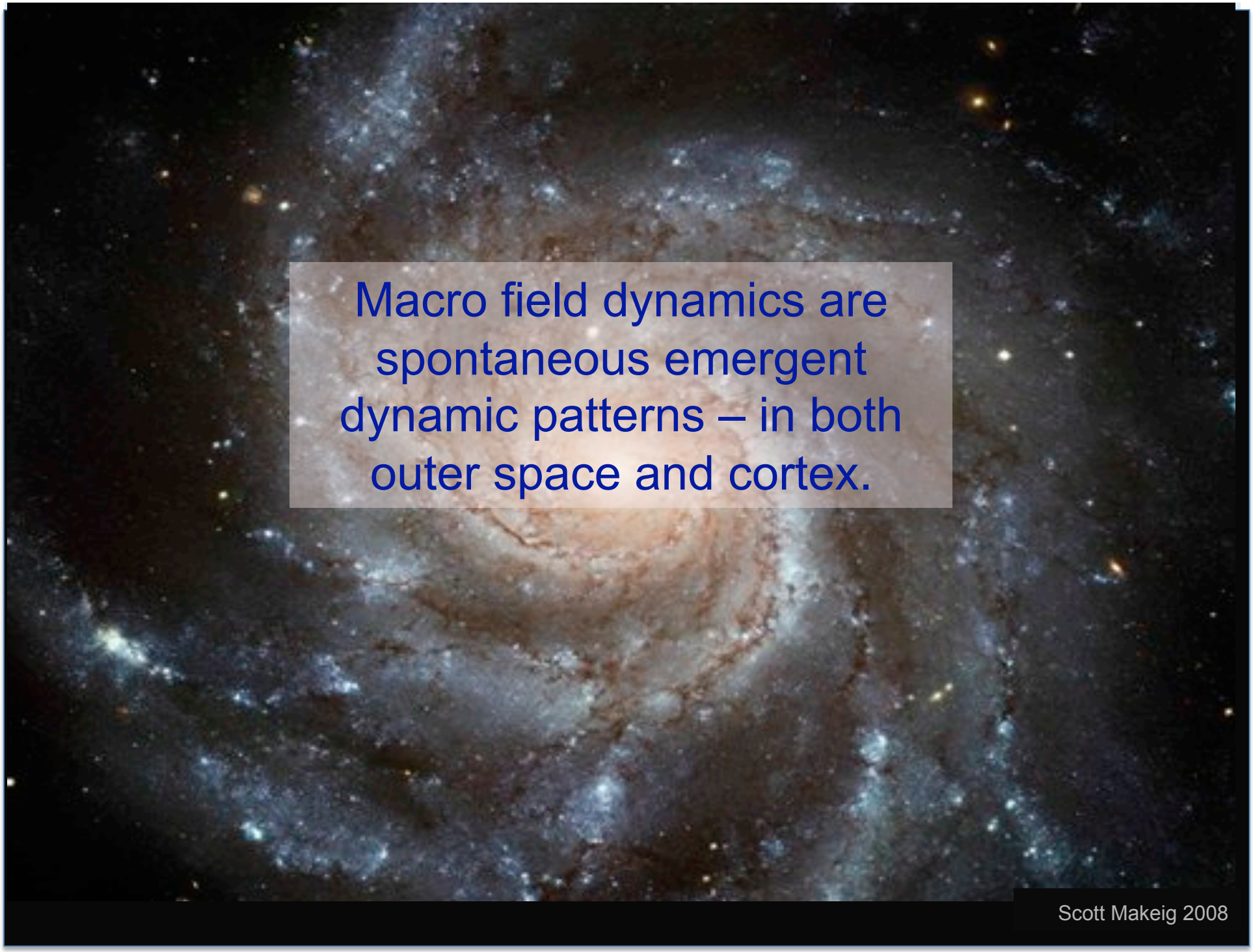
of one aspect of neural activity.

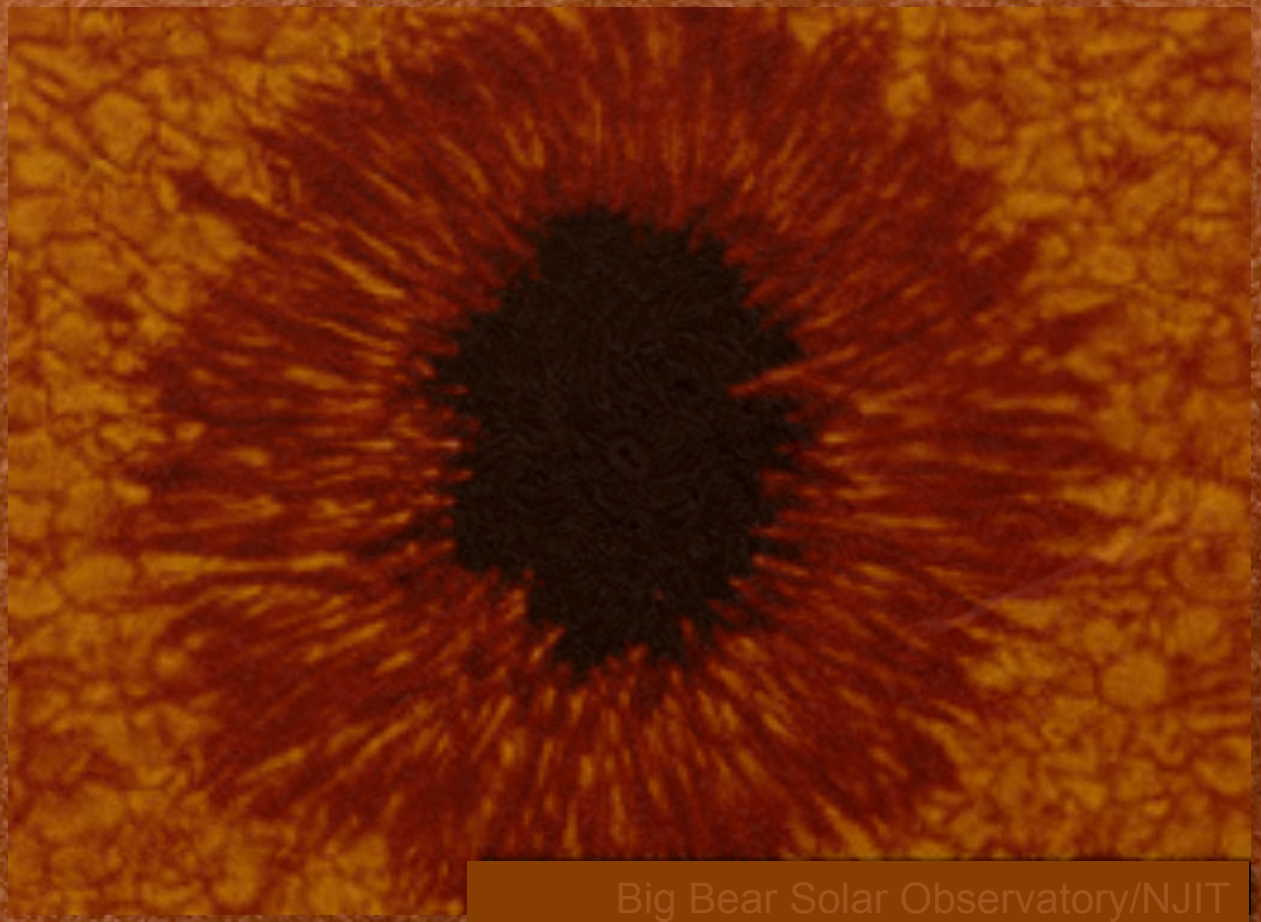
Phase cones (Freeman)

Avalanches (Plenz)

S. Makeig 2010

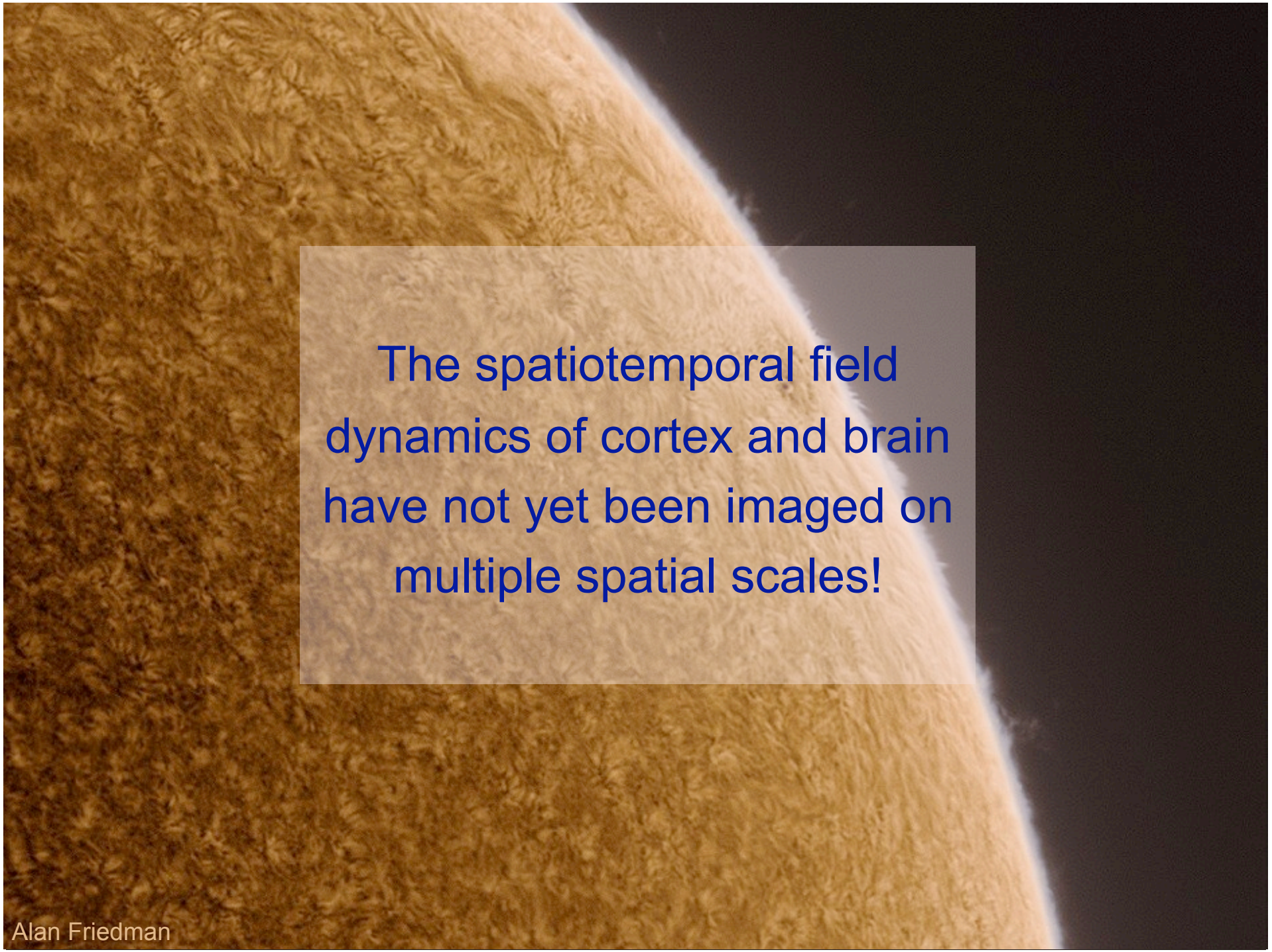


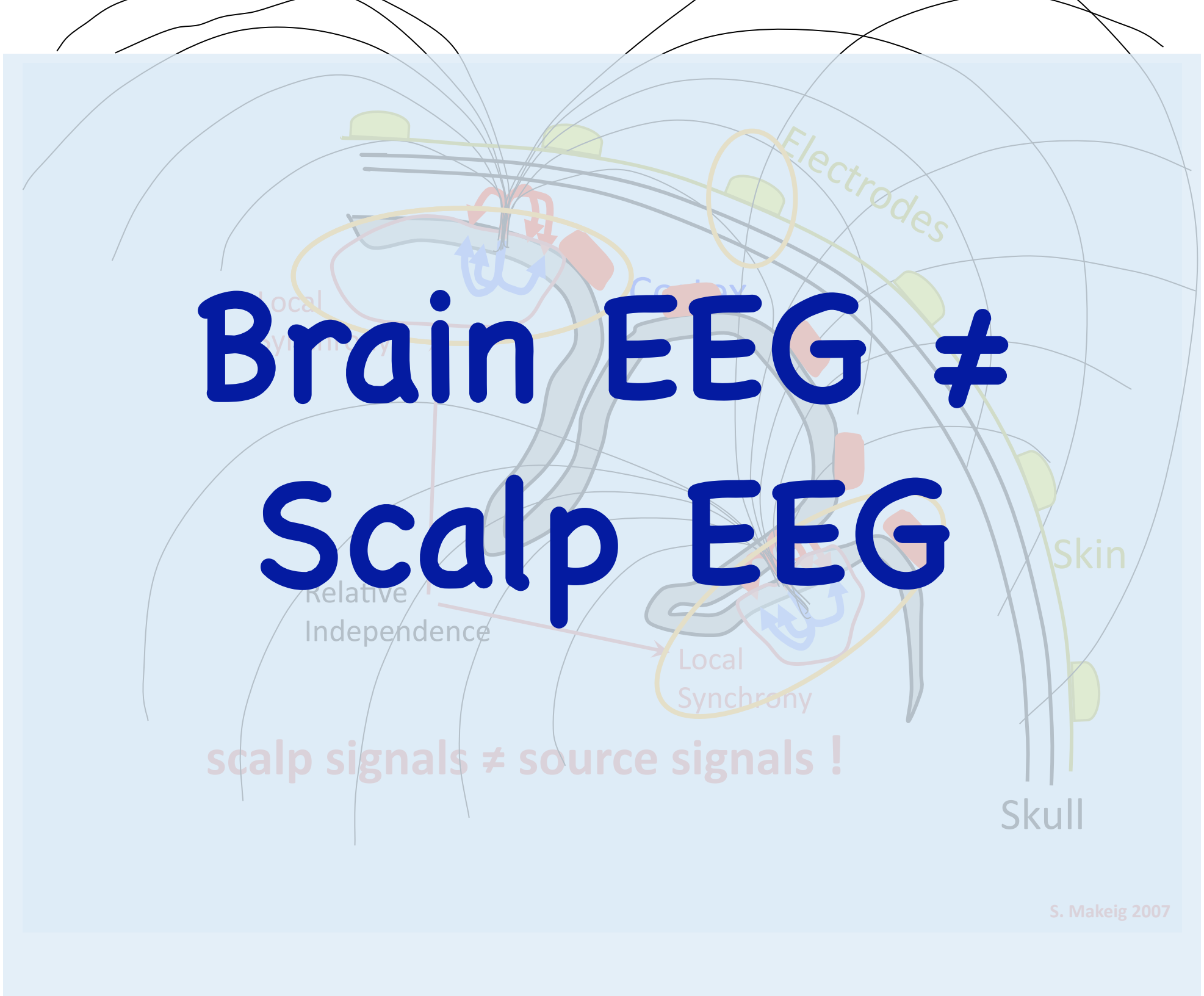

Macro field dynamics are spontaneous emergent dynamic patterns – in both outer space and cortex.
Scott Makeig 2008



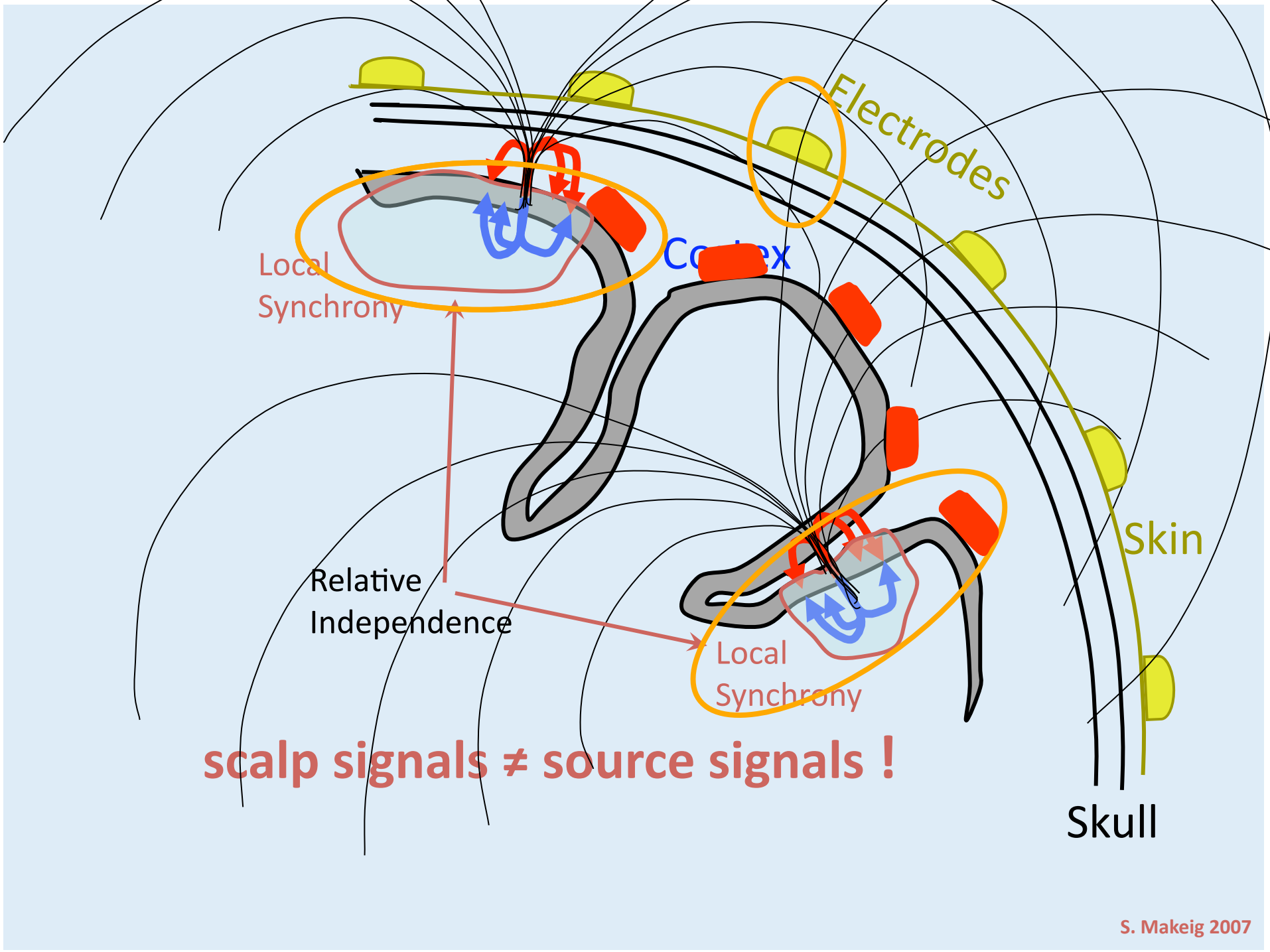
Big Bear Solar Observatory/NJIT

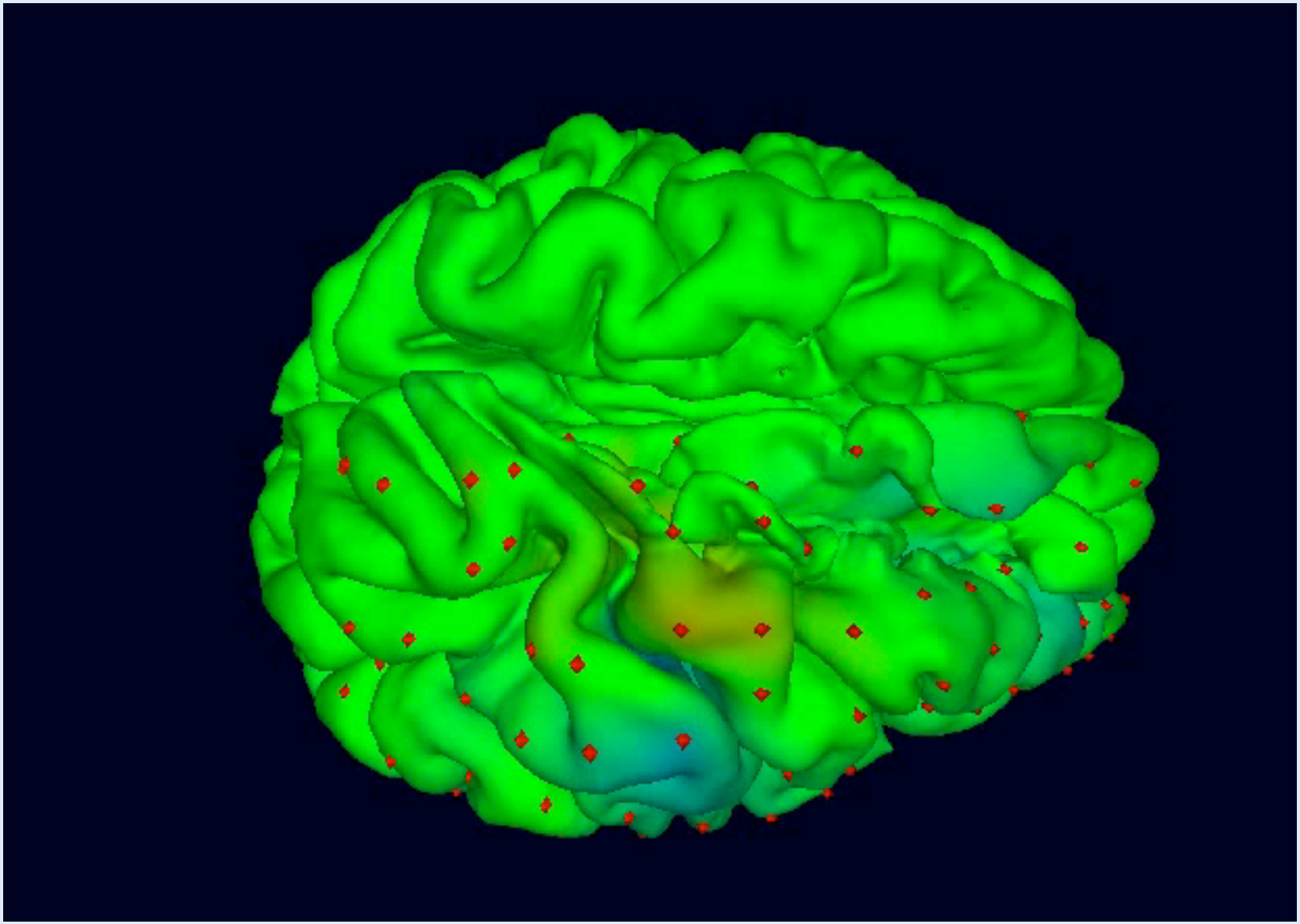
Alan Friedman


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



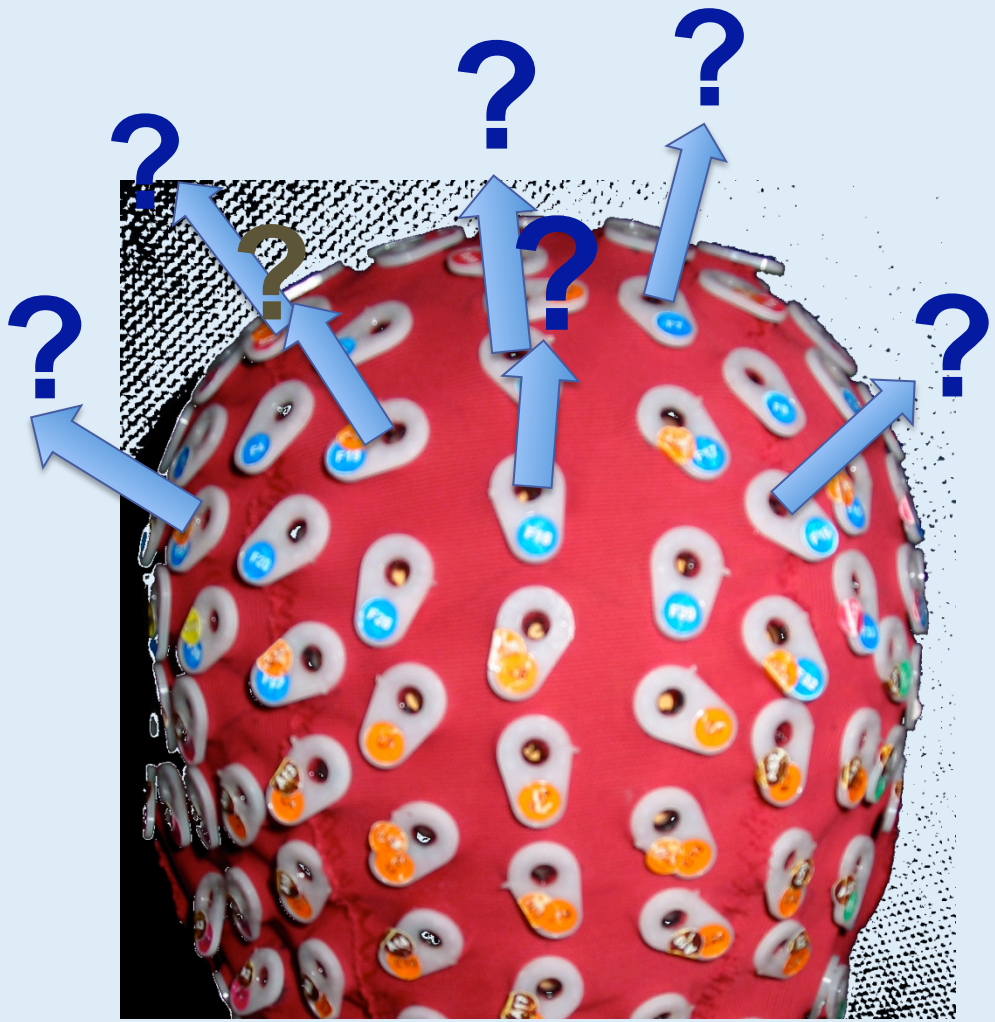
Brain EEG ≠ Scalp EEG


Electrodes
Local
Synchrony
Cortex
Relative
Independence
Local
Synchrony
Skin
Skull
scalp signals ≠ source signals !
S. Makeig 2007

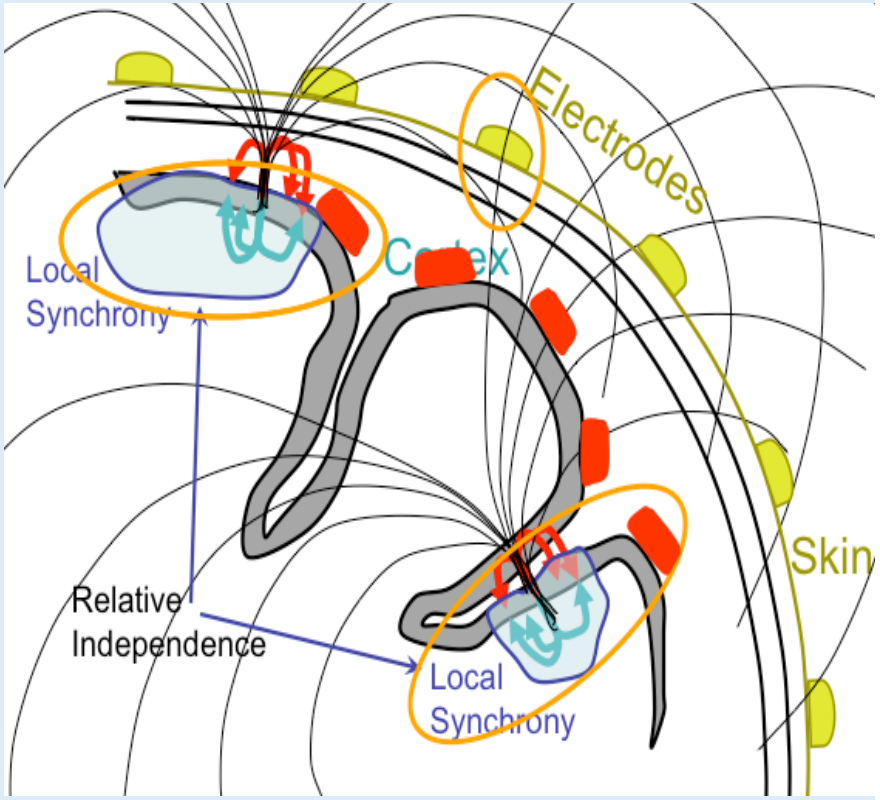


Z. Akalin Acar, J. Palmer, G. Worrell, & Makeig 2010

Naïve 2-D interpretation of EEG signals?



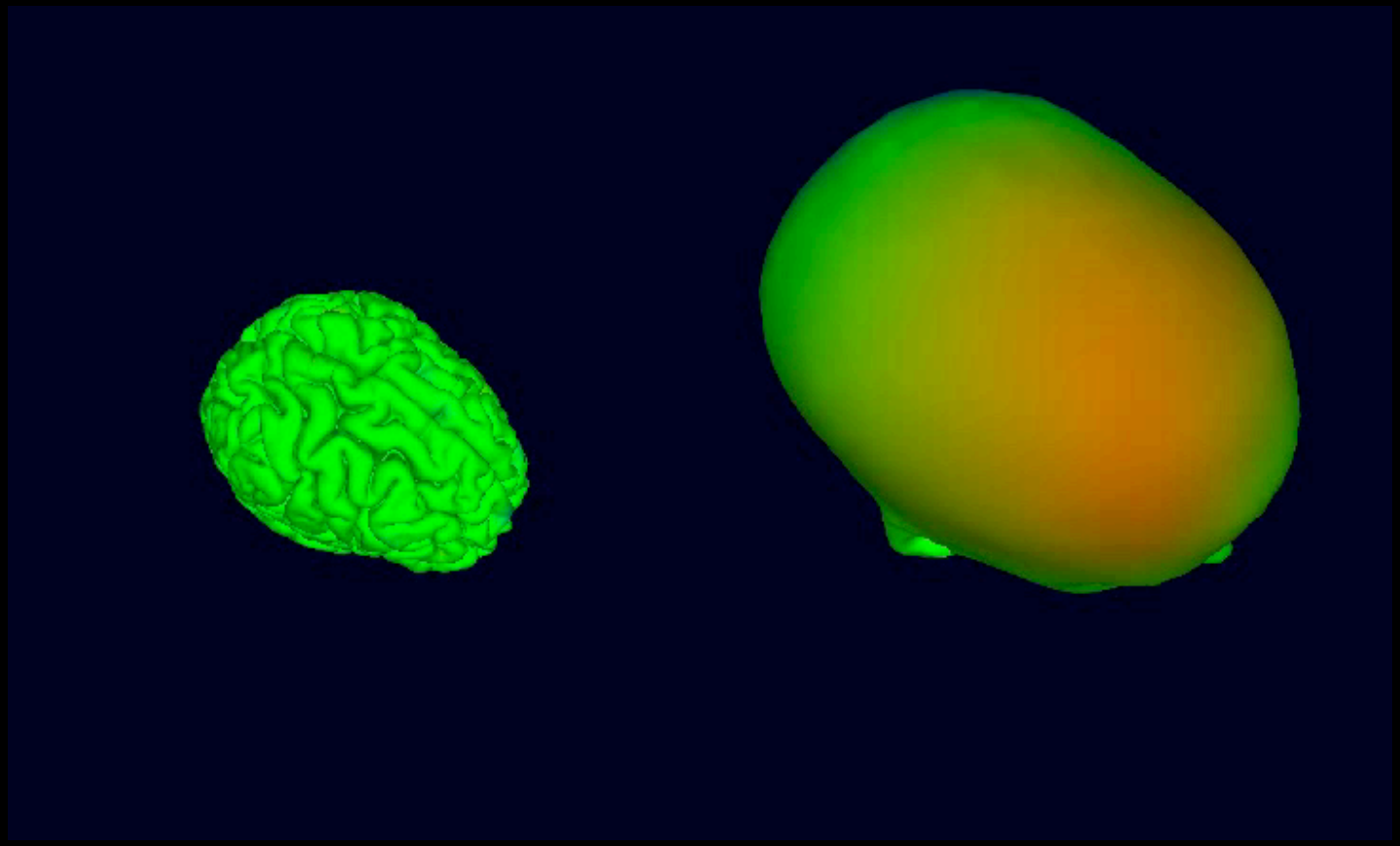
Cortical EEG signal projection patterns as point processes



Actual cortical source volume conduction patterns (cartoon)

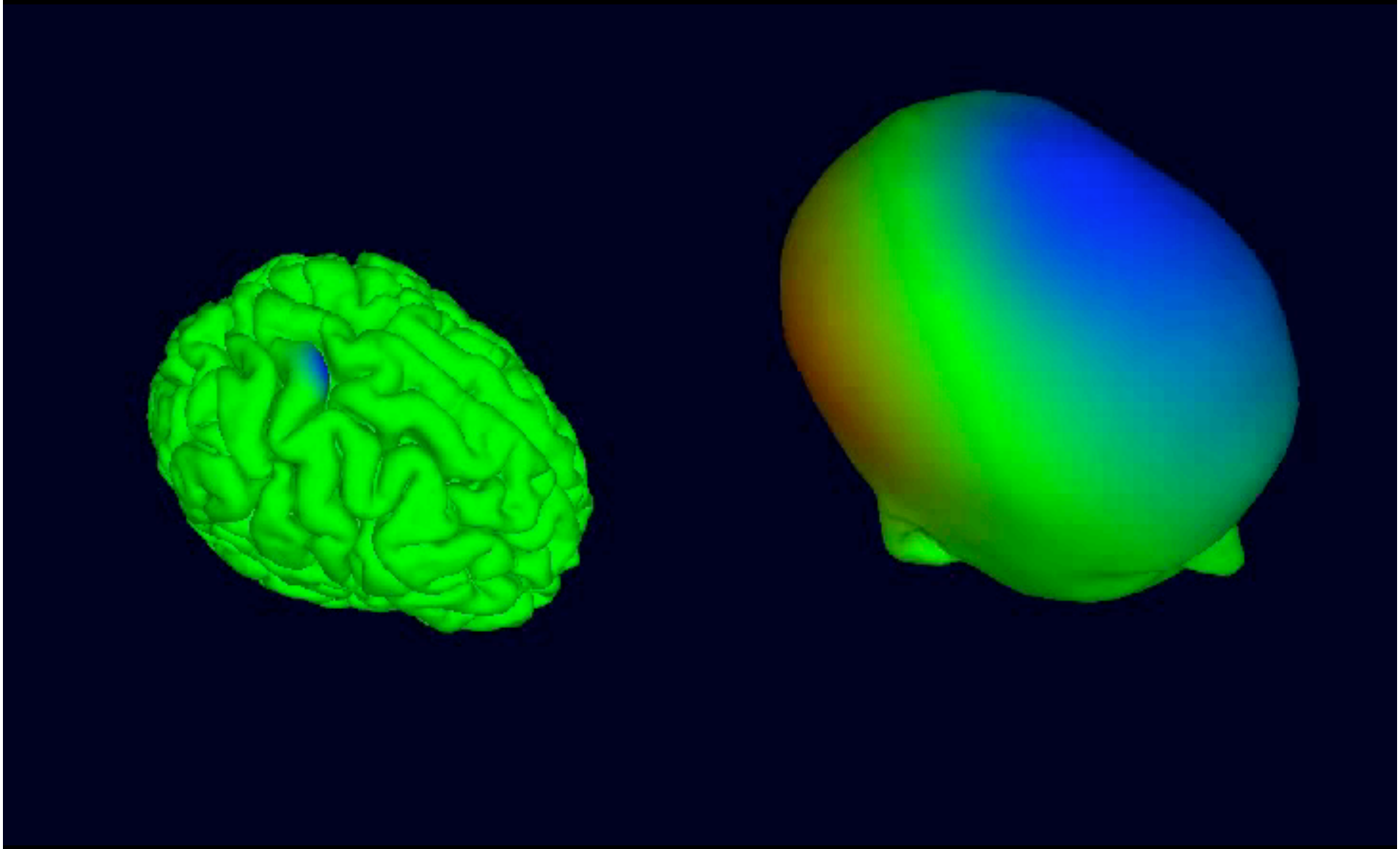
“Surely, Dr. Lowe, if there were gravity waves, we would have detected them by now.”

The very broad EEG point-spread function



Z. Akalin Acar & S. Makeig 2010

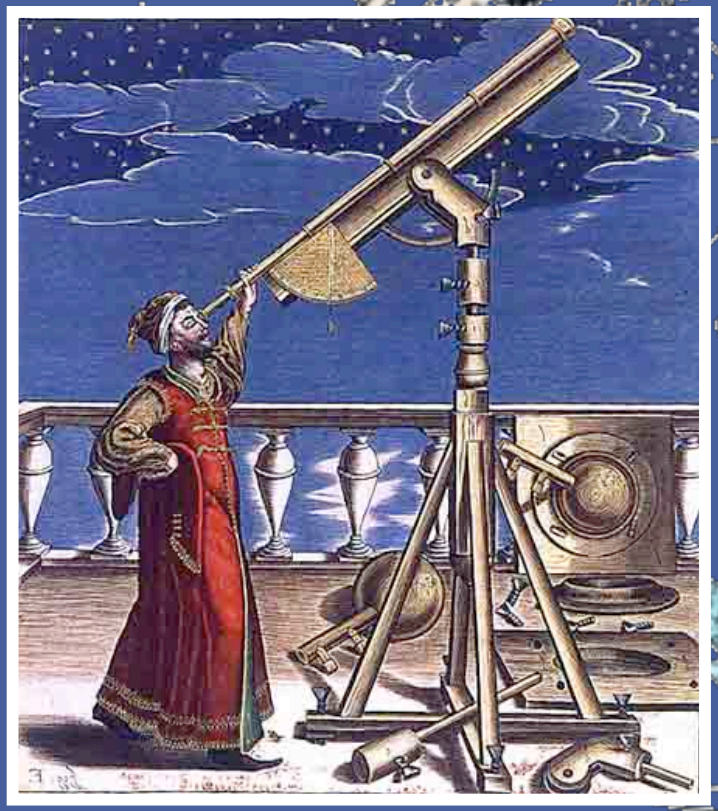
The very broad EEG point-spread function



Single spatially labile source

Akalin Acar & Makeig 2010

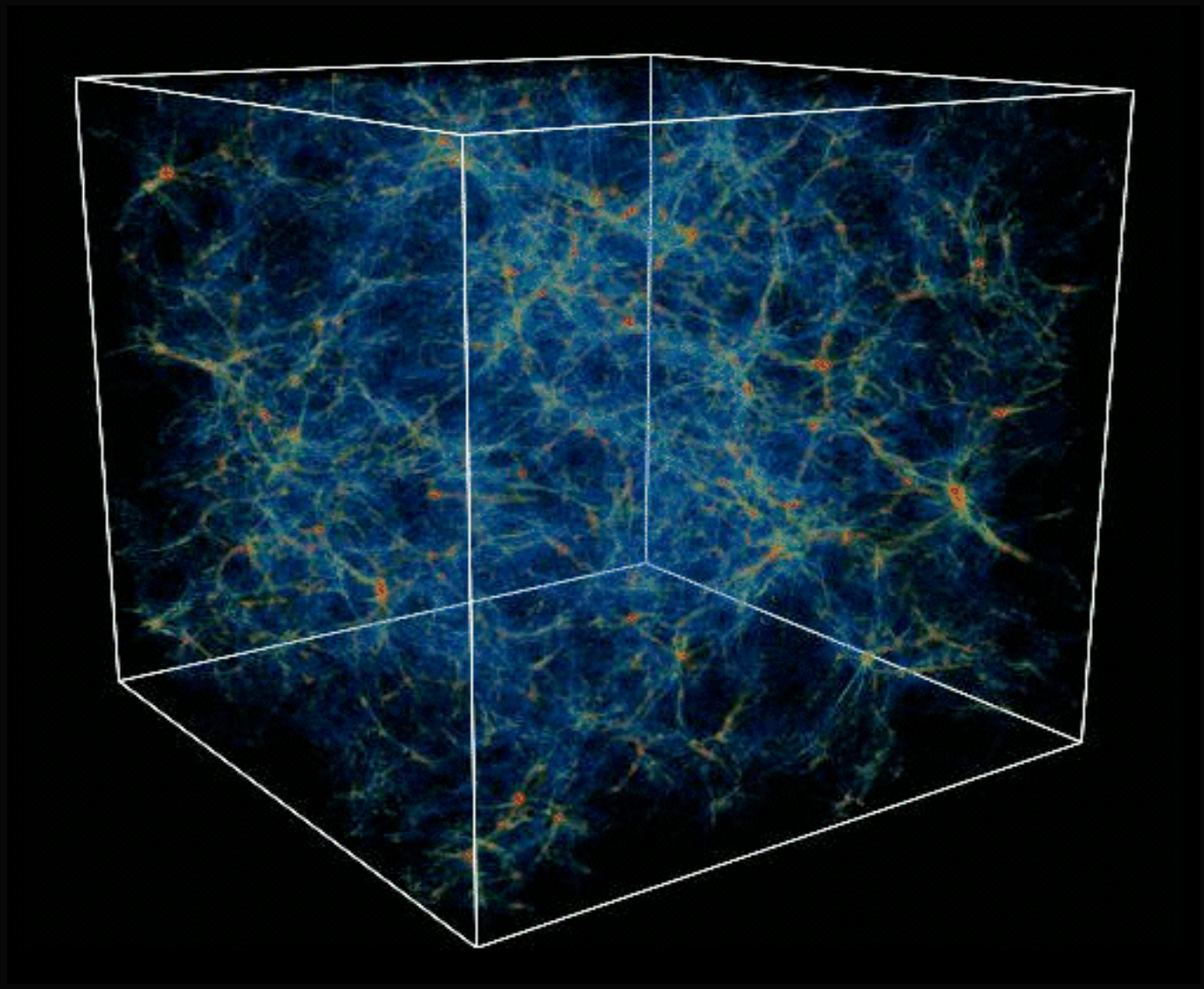
The 2-D Dome of the Sky



Scott Makeig 2008

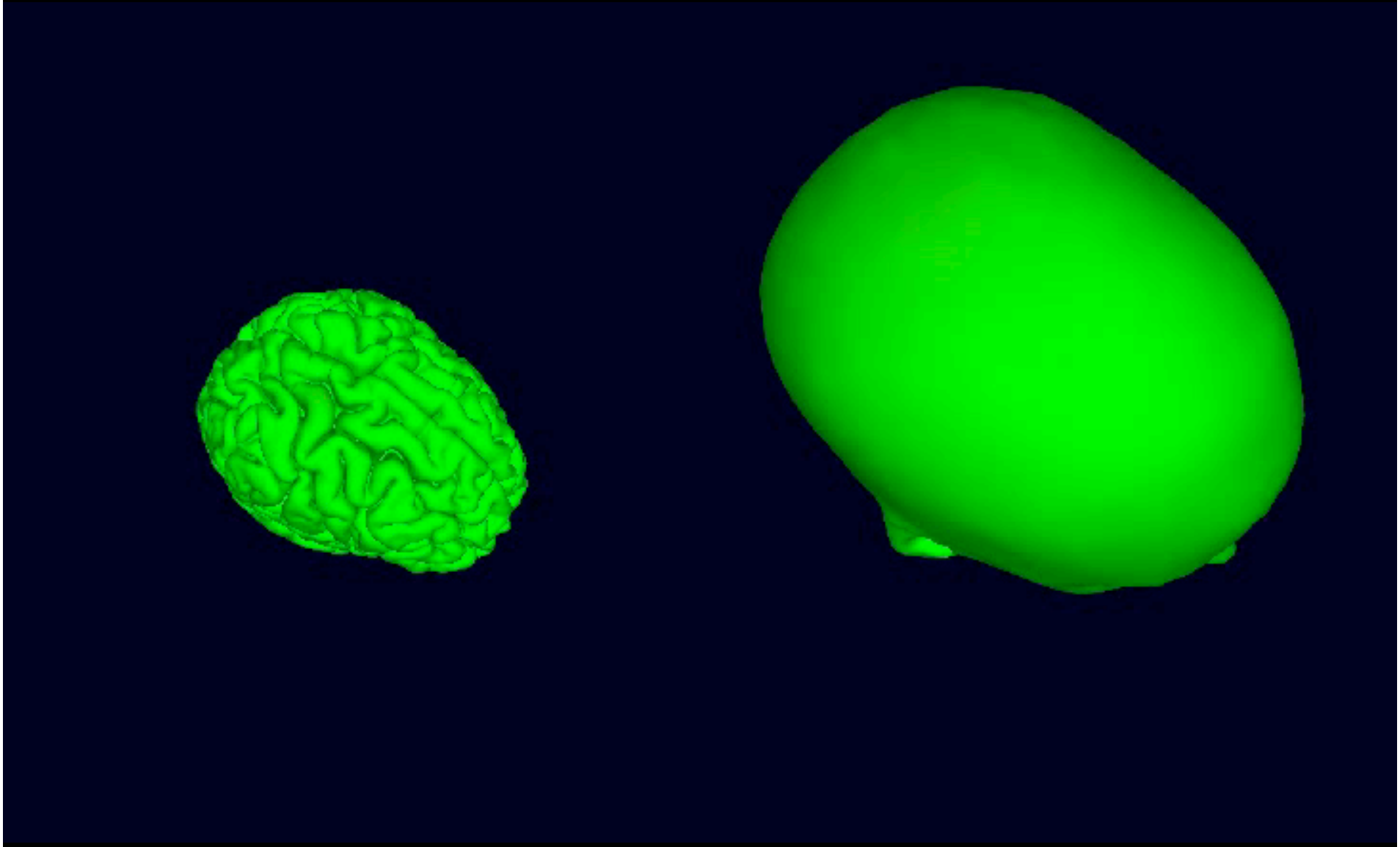
Stephen L. Alvarez

3-D structure of the Universe



NASA 2009

The very broad EEG point-spread function

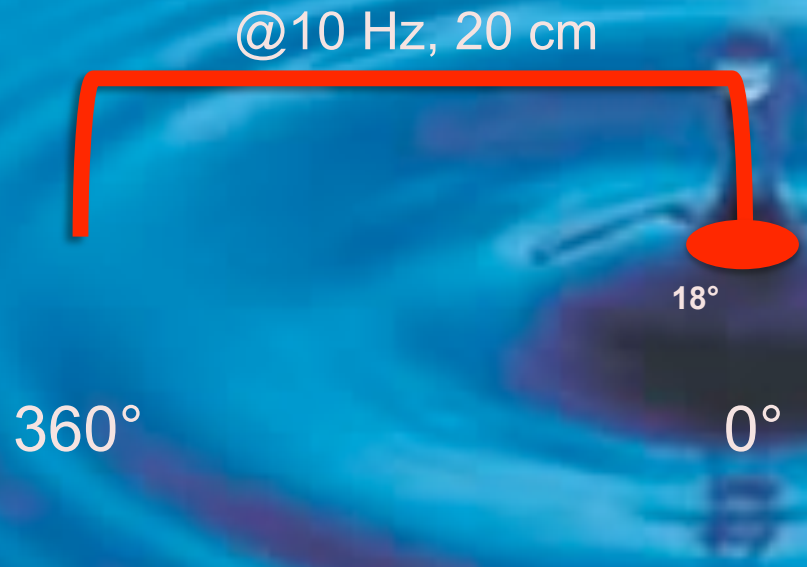


Spatially static cortical patch source

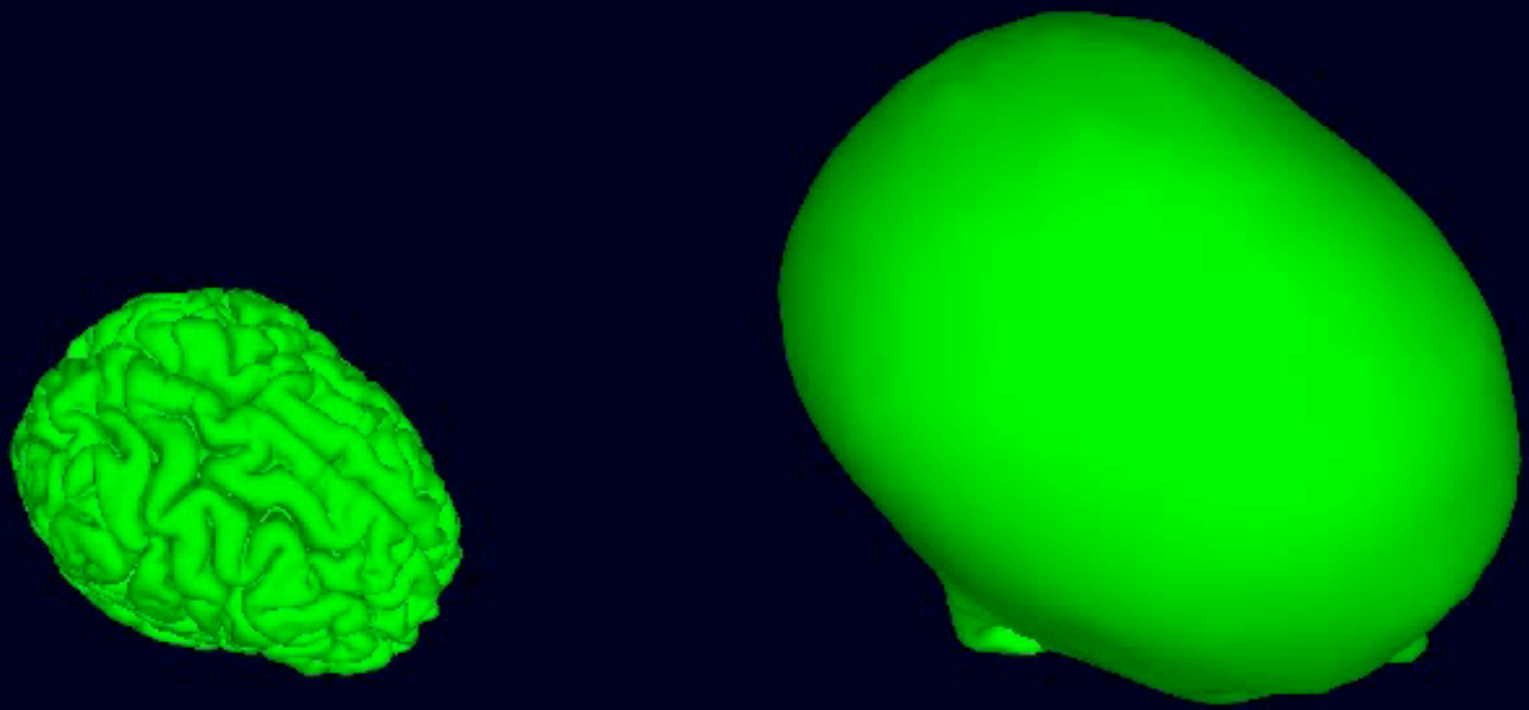
Z. Akalin Acar & S. Makeig 2010

Phase cones (Freeman)

Avalanches (Plenz)



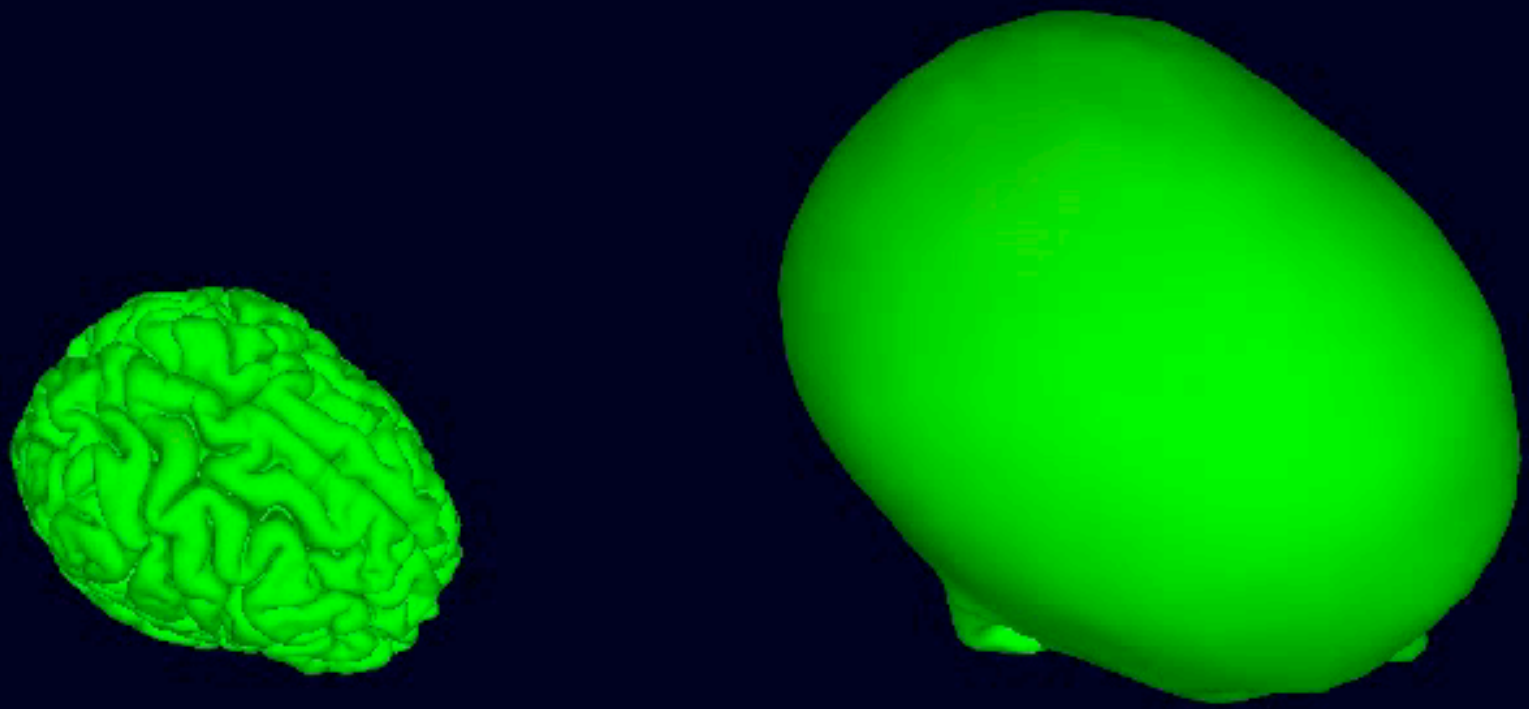
The very broad EEG point-spread function



Phase lag, center to edge: 18°

Z. Akalin Acar & S. Makeig 2010

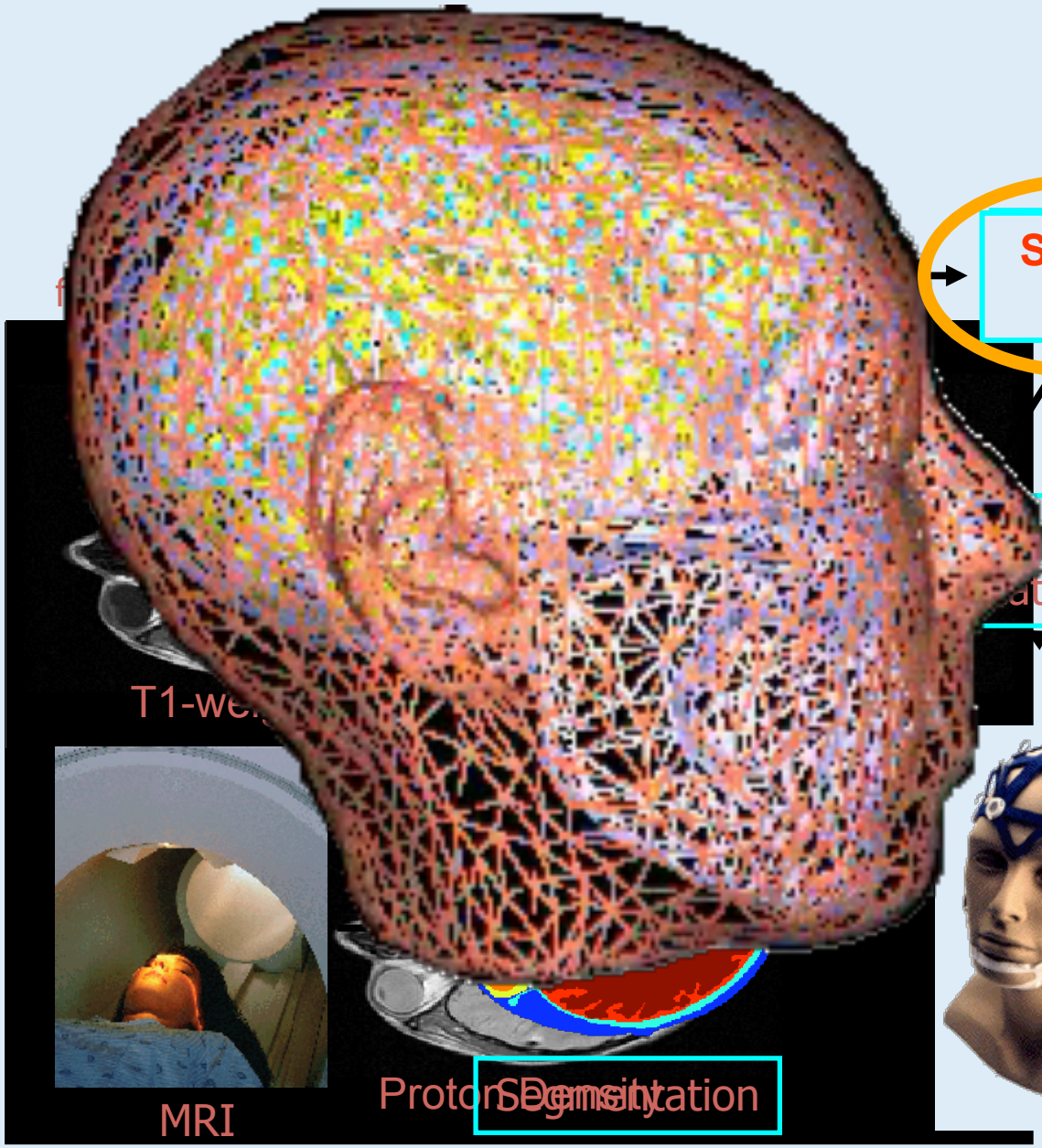
The very broad EEG point-spread function



Phase lag, center to edge: 0°

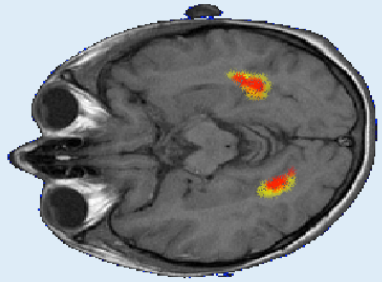
Akalin Acar & Makeig 2010

Electromagnetic source localization



MRI

Simple Map

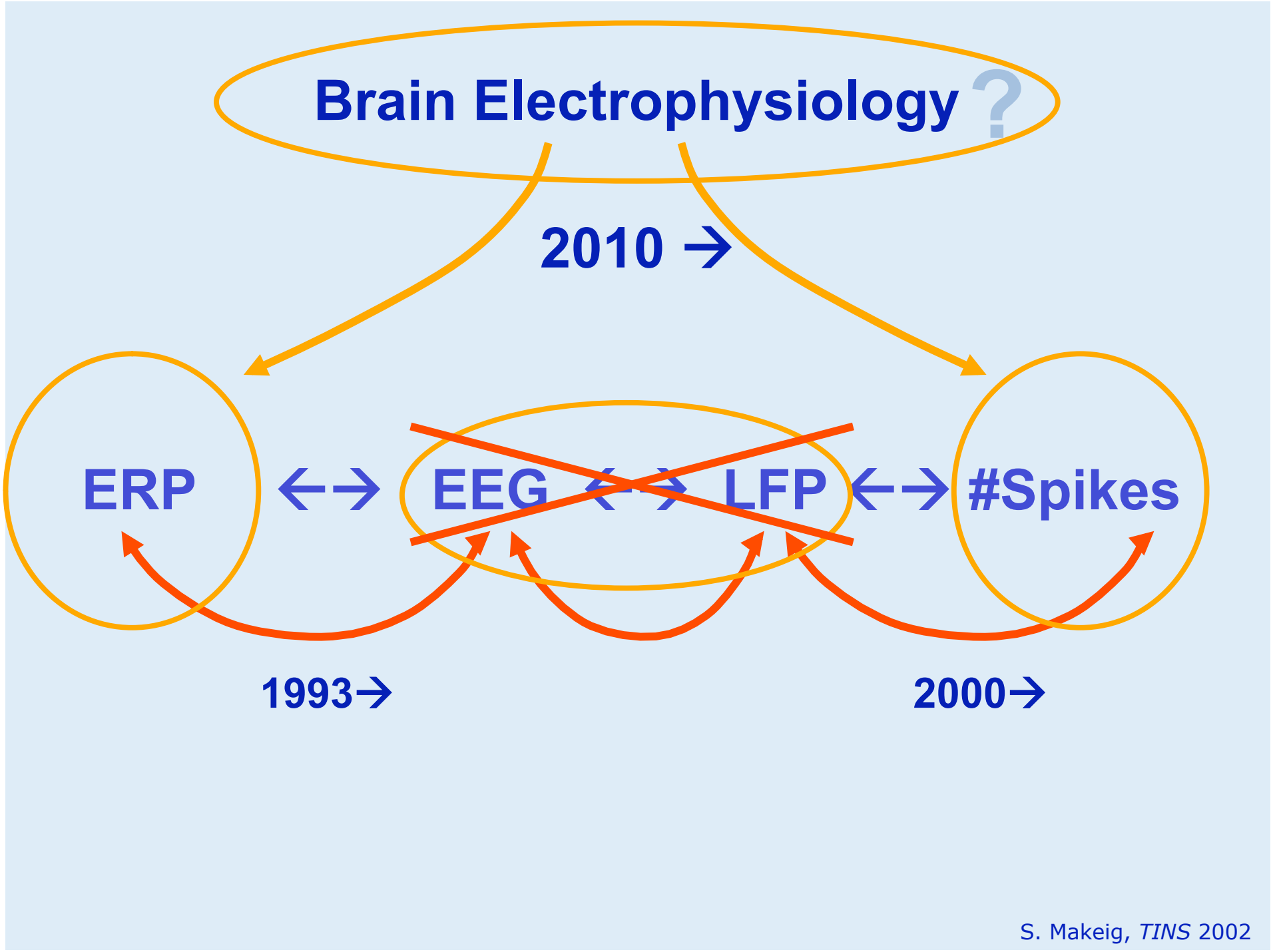


Source Image

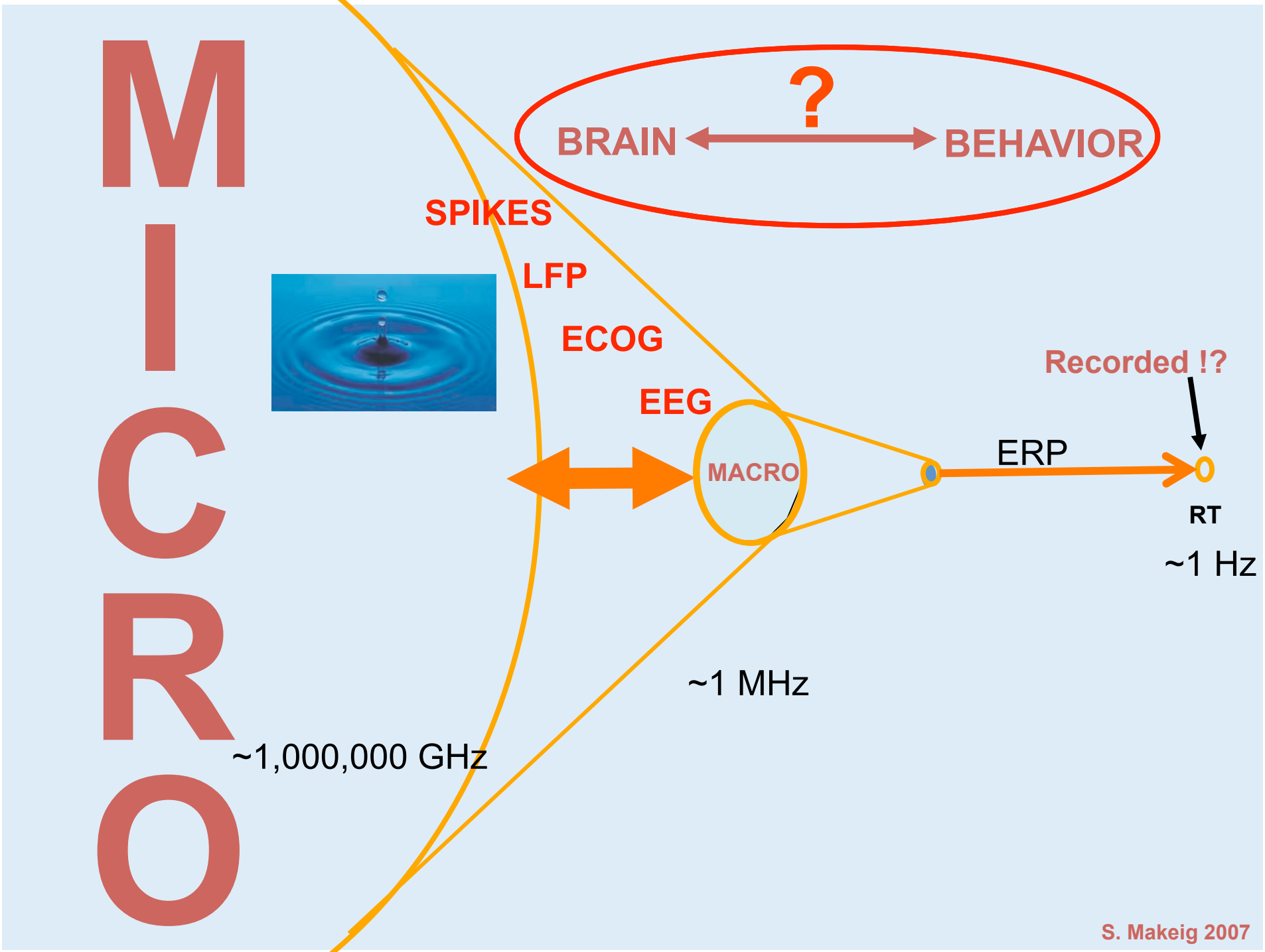
Signal Processing

EEG/MEG

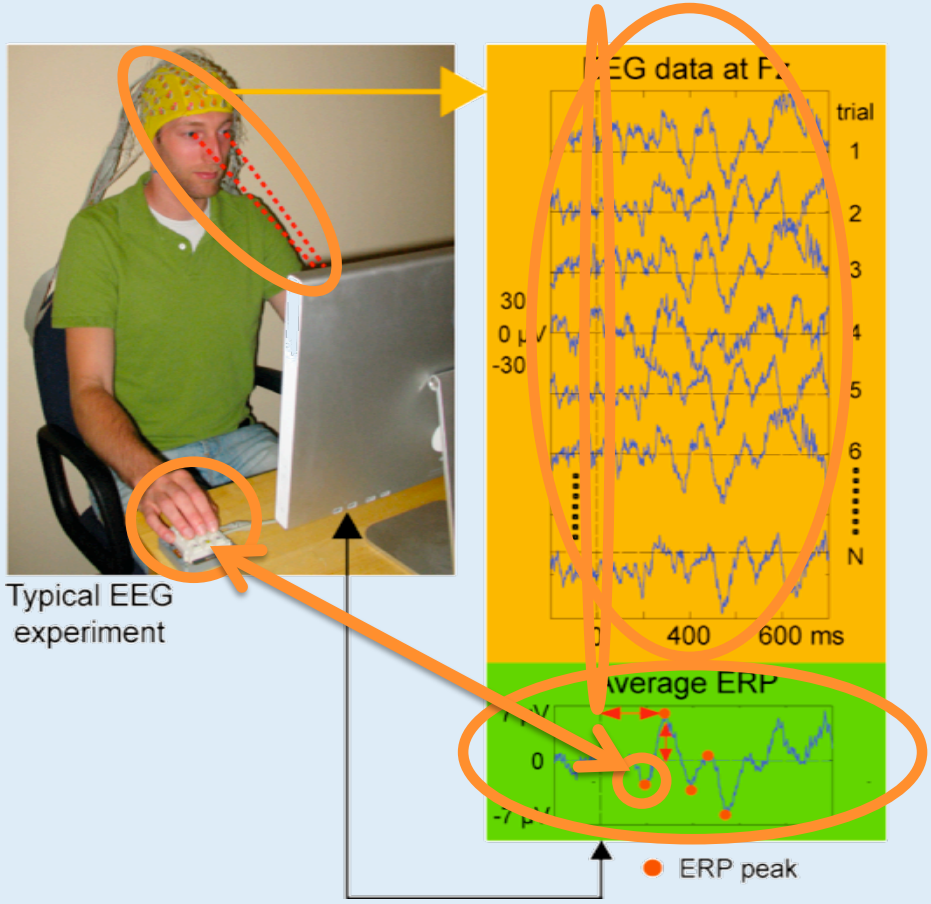
Zeynep Akalin Acar, & Scott Makeig '06



S. Makeig, *TINS* 2002

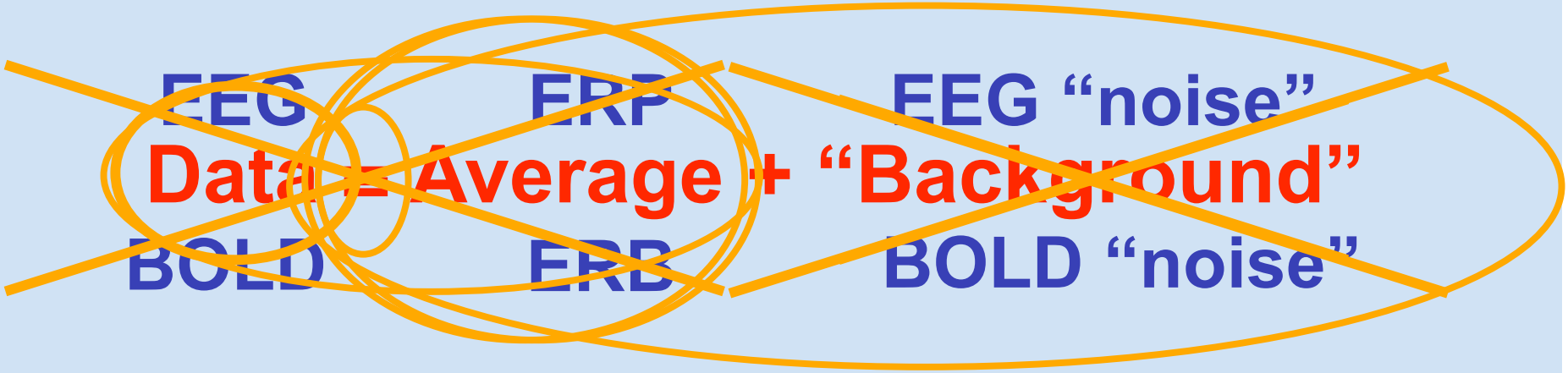

MICRO
BRAIN
?
BEHAVIOR
SPIKES
LFP
ECOG
EEG
MACRO
ERP
Recorded !?
RT
~1 Hz
~1 MHz
~1,000,000 GHz
S. Makeig 2007

Studying ‘cognitive perception’ using ERPs



Scott Makeig, 2008

The response averaging model:



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

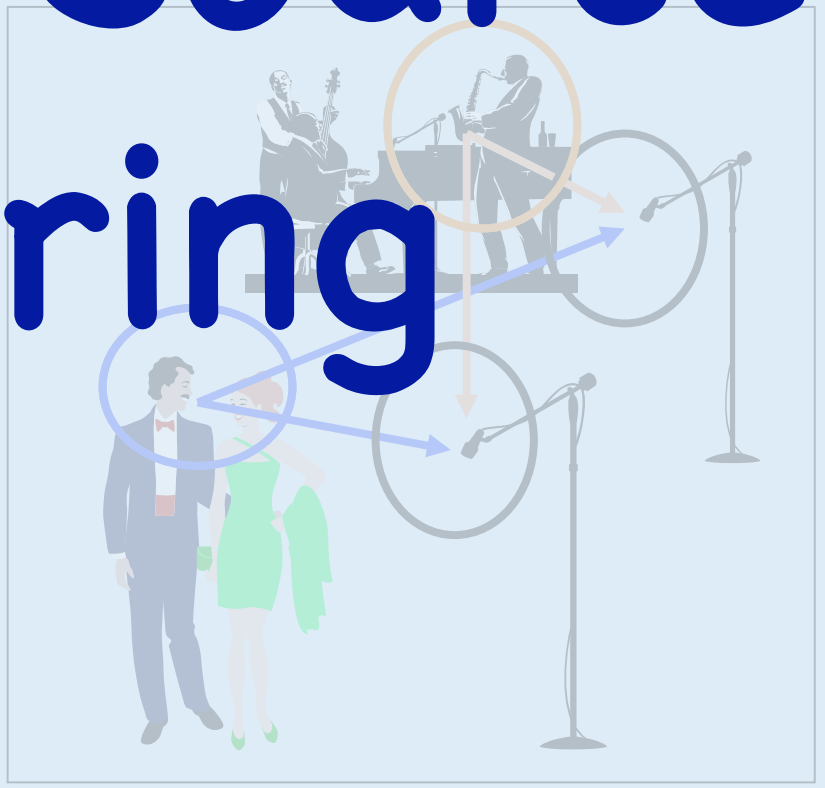
- Reduction of the time series data at each channel to a **single average-response (ERP) time series**.

- 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?

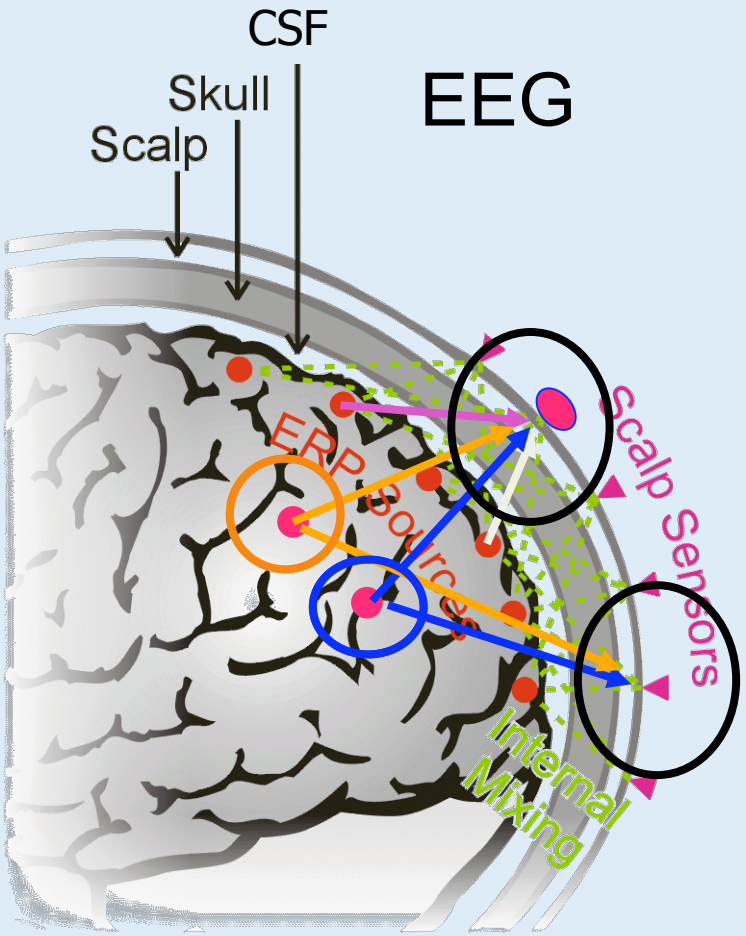
Blind EEG Source Separation by
Independent Component Analysis

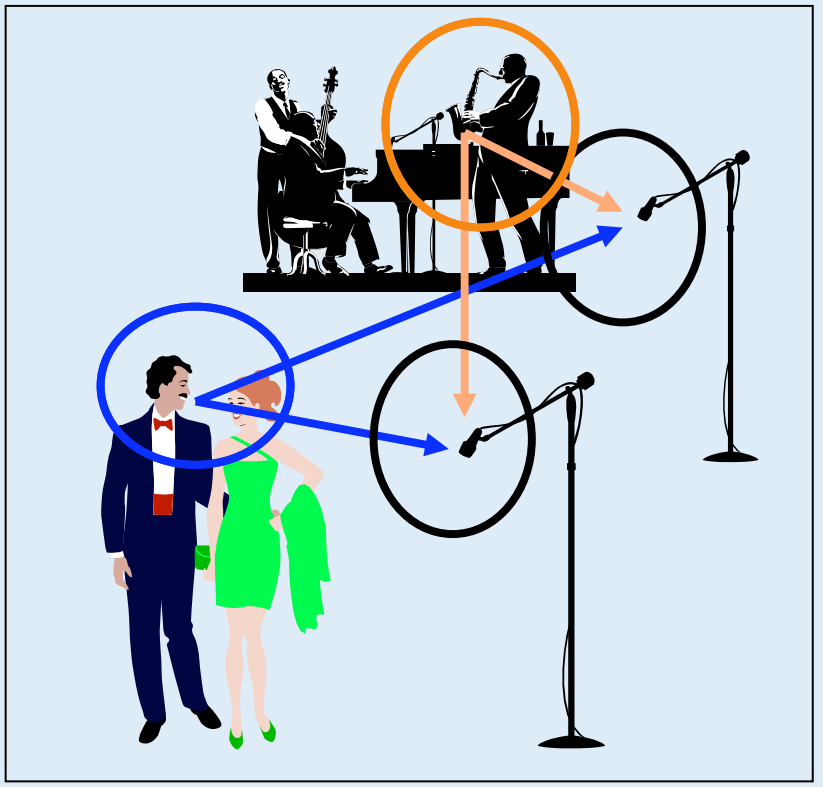
Spatial Source Filtering



S. Makeig (2000)

Blind EEG Source Separation by Independent Component Analysis





S. Makeig (2000)

Independent Component Analysis of Electroencephalographic Data

Scott Makeig
Naval Health Research Center

Anthony J. Bell
Computational Neurobiology Lab
The Salk Institute

Tzyy-Ping Jung
Naval Health Research Center and
Computational Neurobiology Lab
The Salk Institute

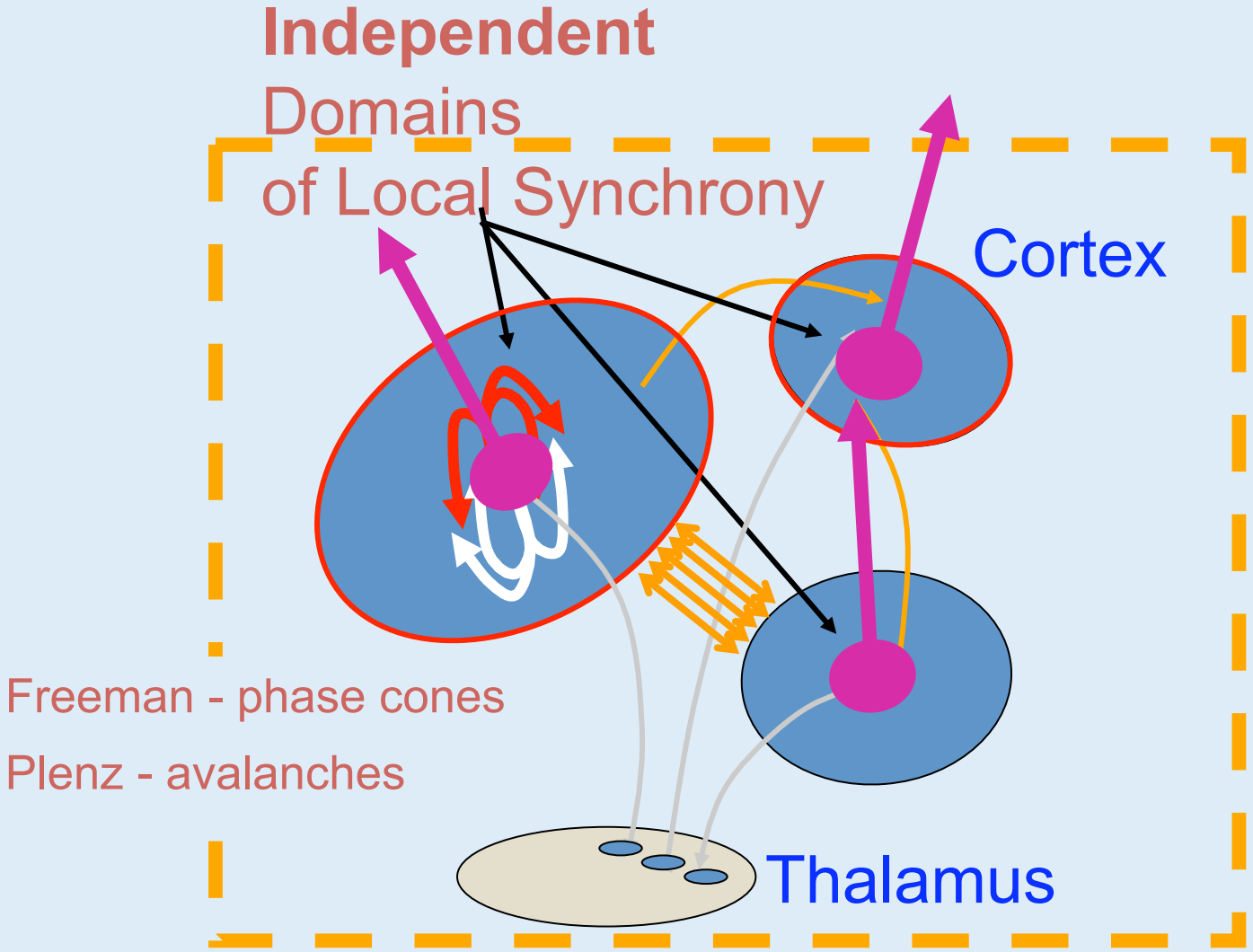
Terrence J. Sejnowski
Howard Hughes Medical Institute and
Computational Neurobiology Lab
The Salk Institute

Abstract

Infomax ICA

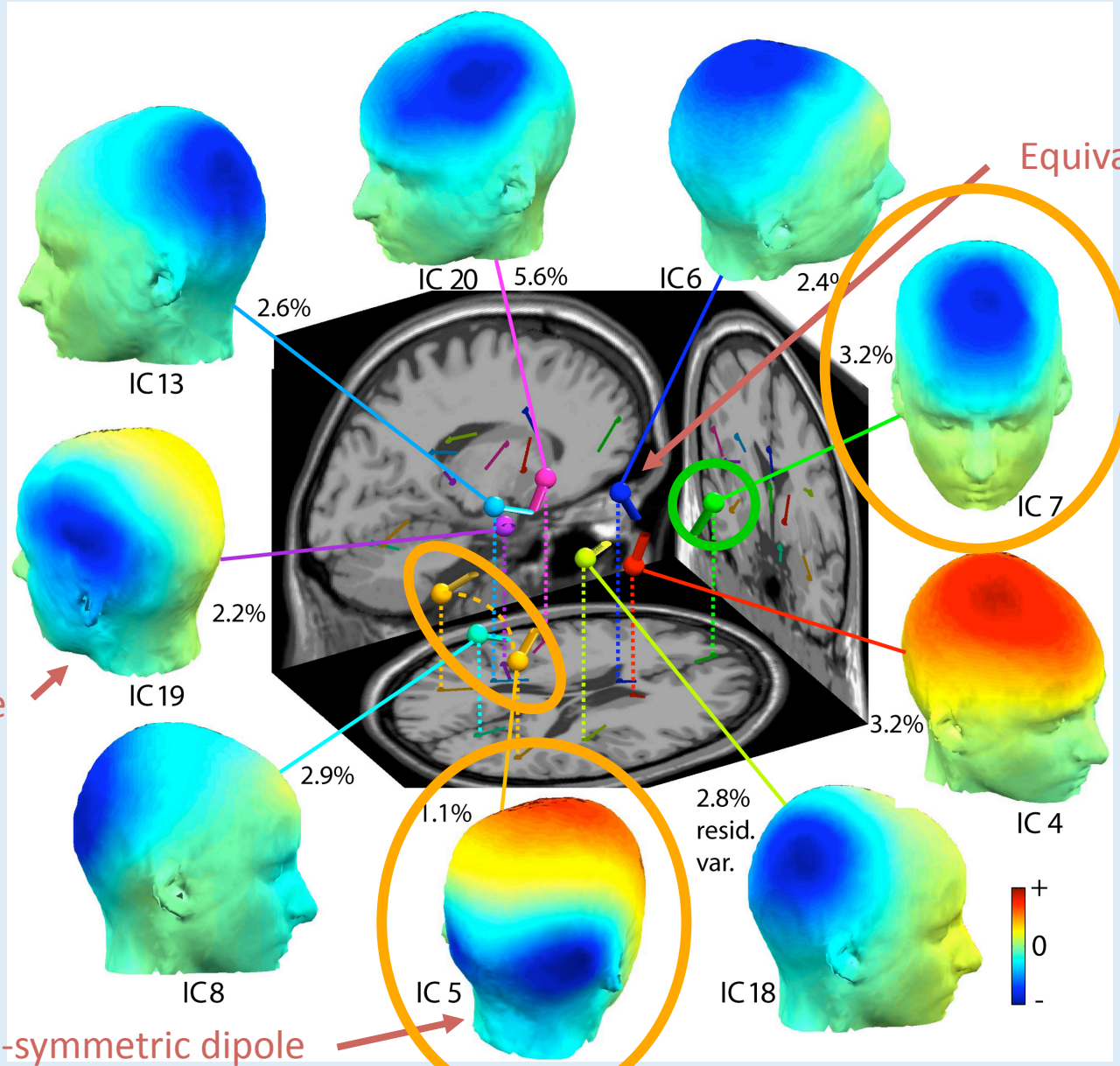
Makeig et al., NIPS95

Are EEG source outputs (nearly) independent?



S. Makeig (2007)

Independent brain EEG sources



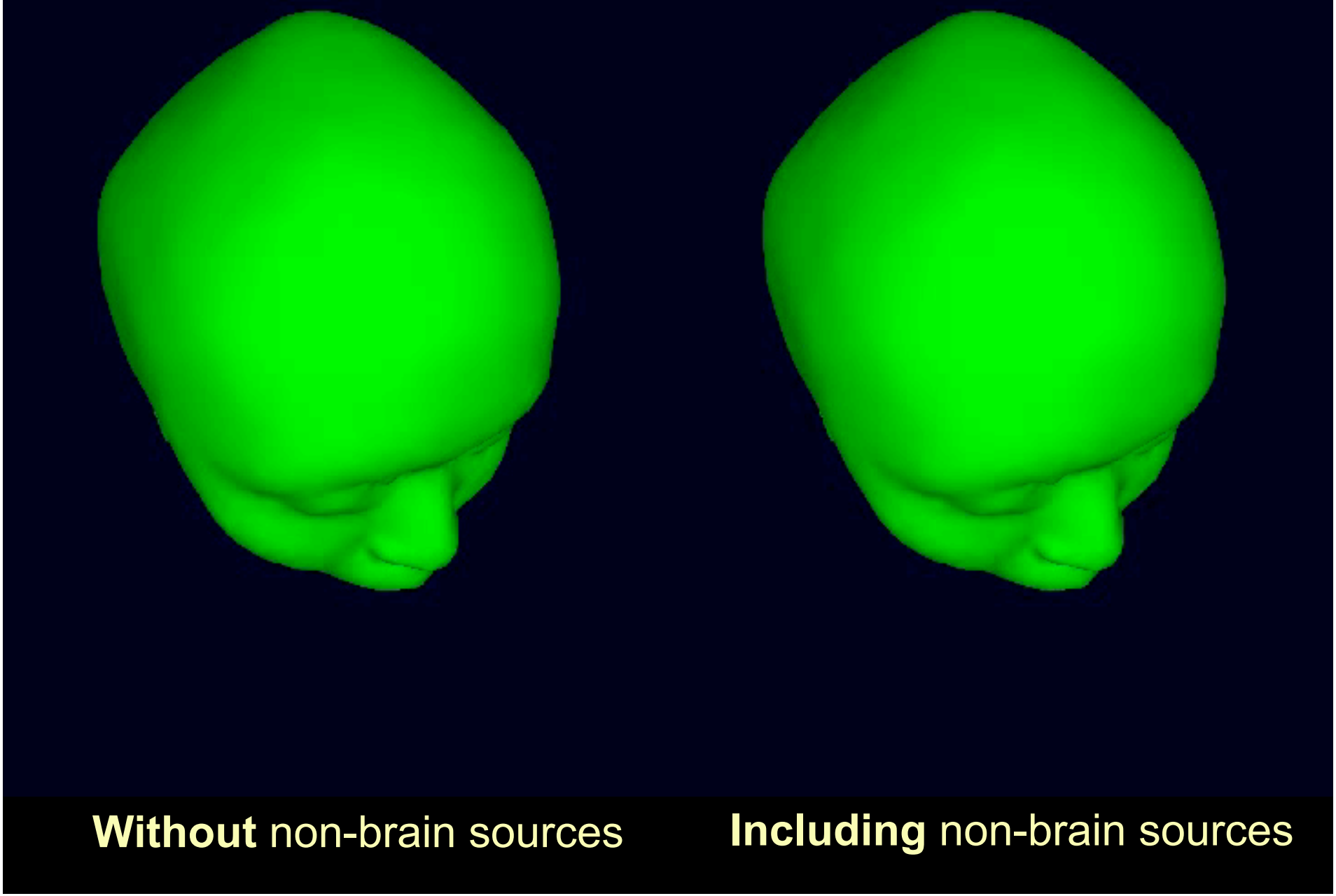
Equivalent dipoles

Single dipole source

Dual-symmetric dipole source

Julie Onton & S. Makeig (2006)

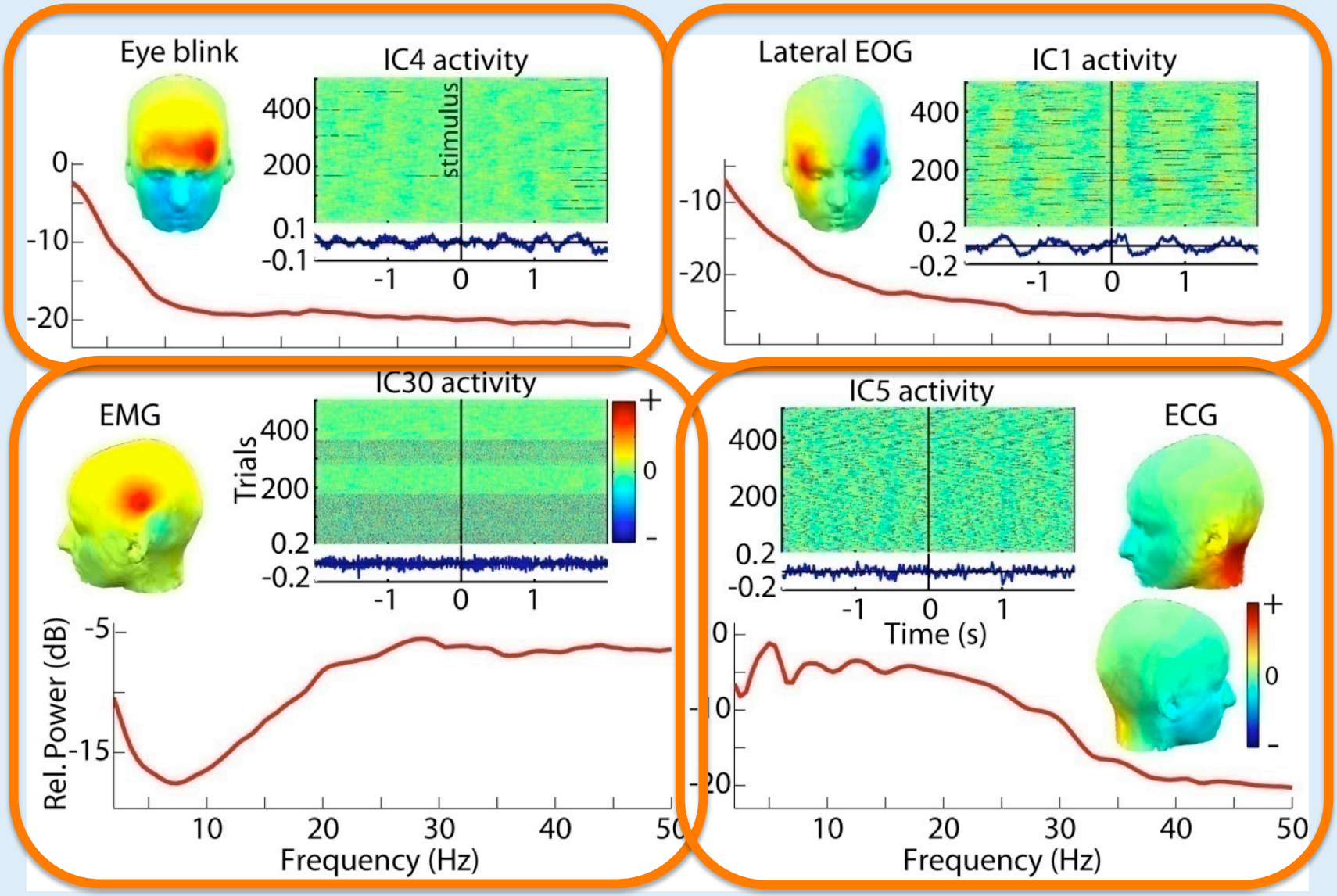
Effects of non-brain artifacts on scalp EEG



Without non-brain sources

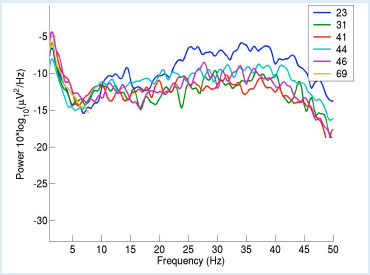
Including non-brain sources

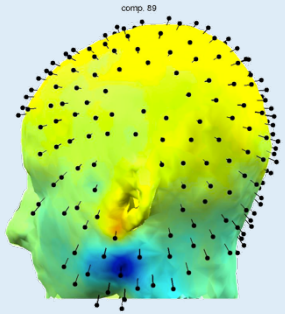
Some non-brain source ICs

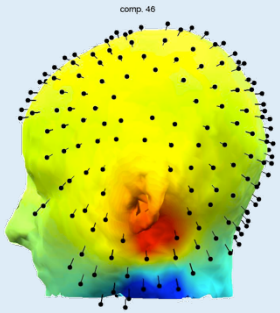


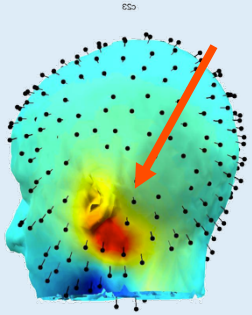
Onton & Makeig, 2006

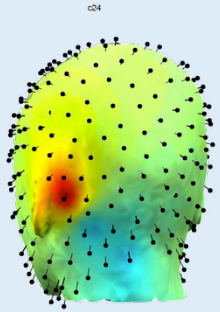
Independent muscle signals

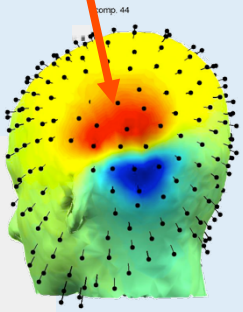


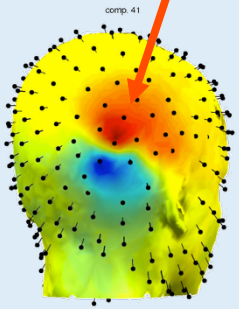


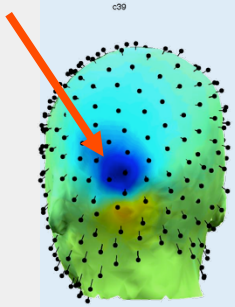


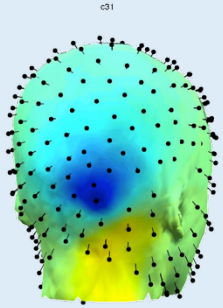


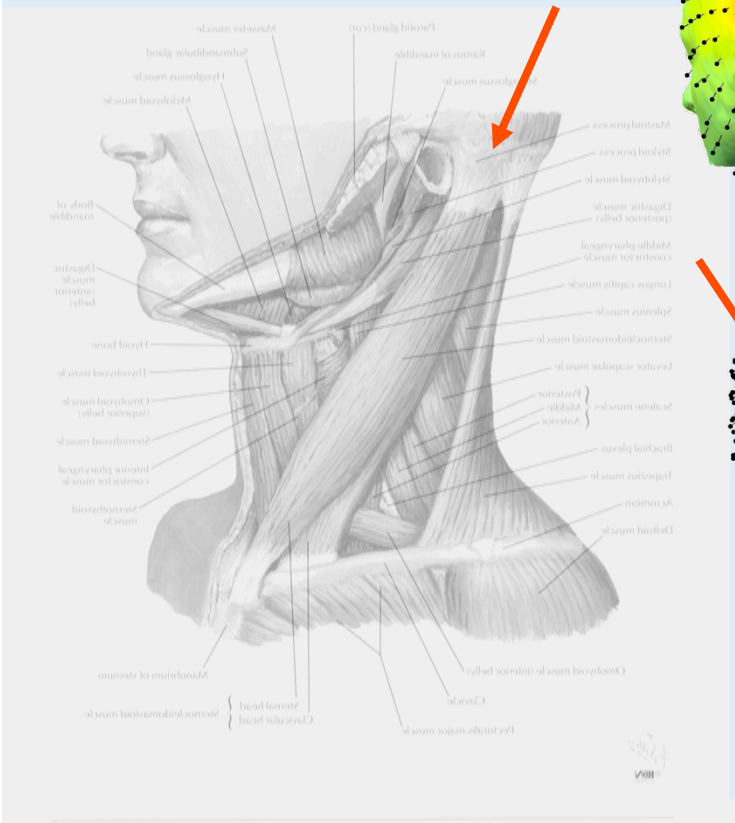


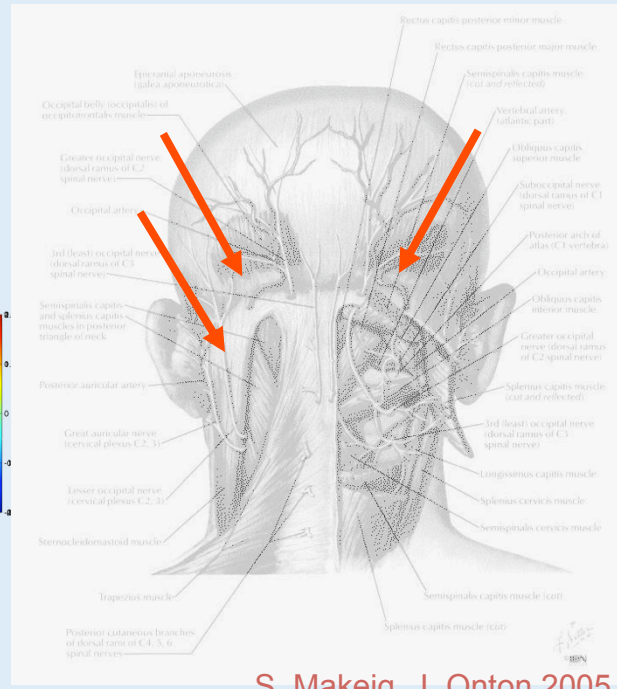






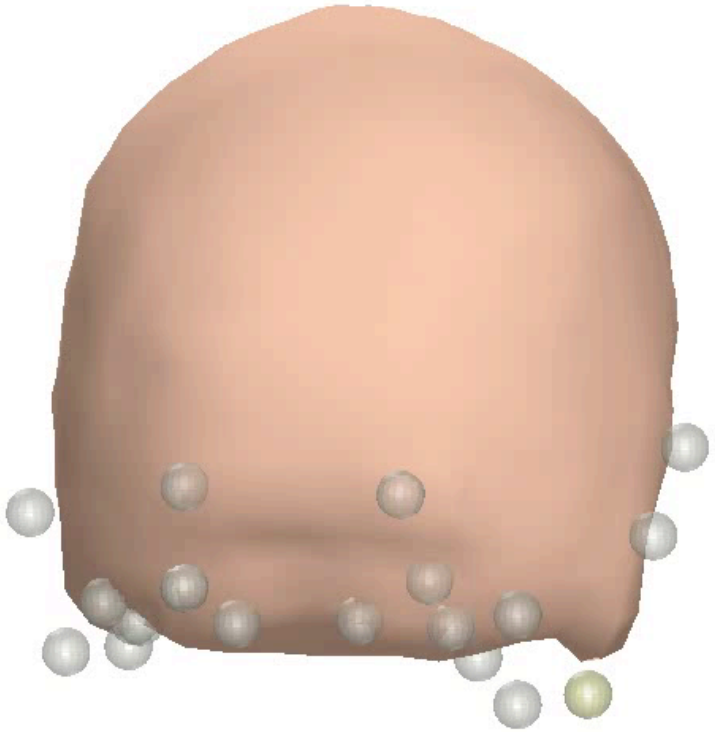


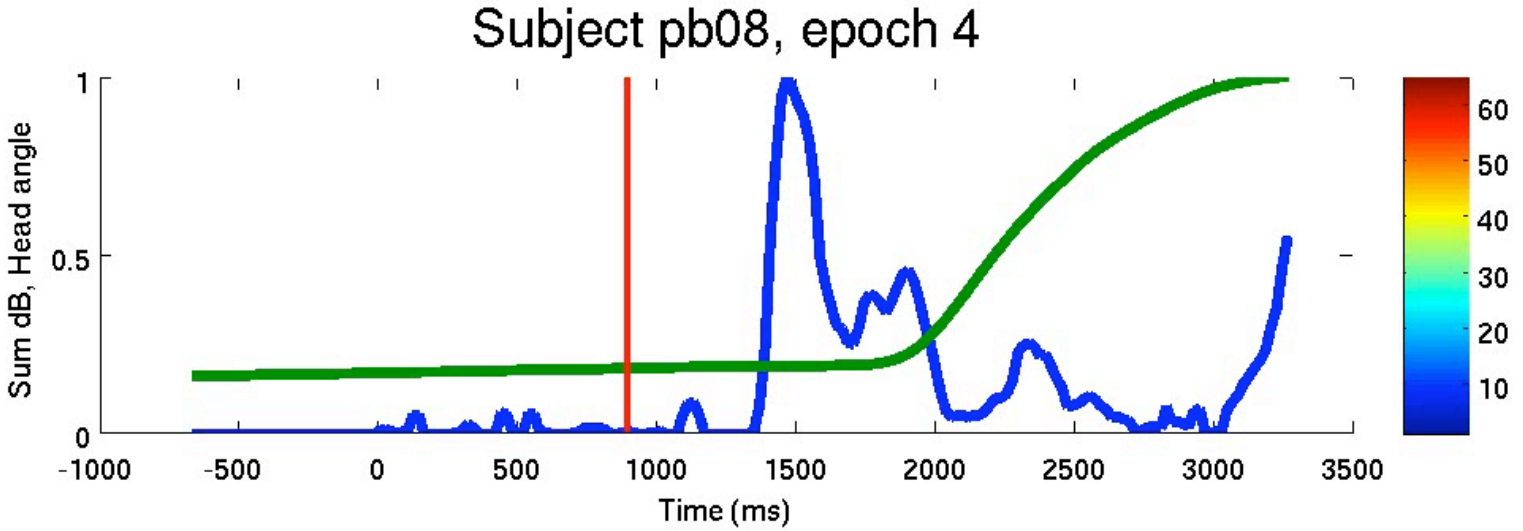




S. Makeig, J. Onton 2005

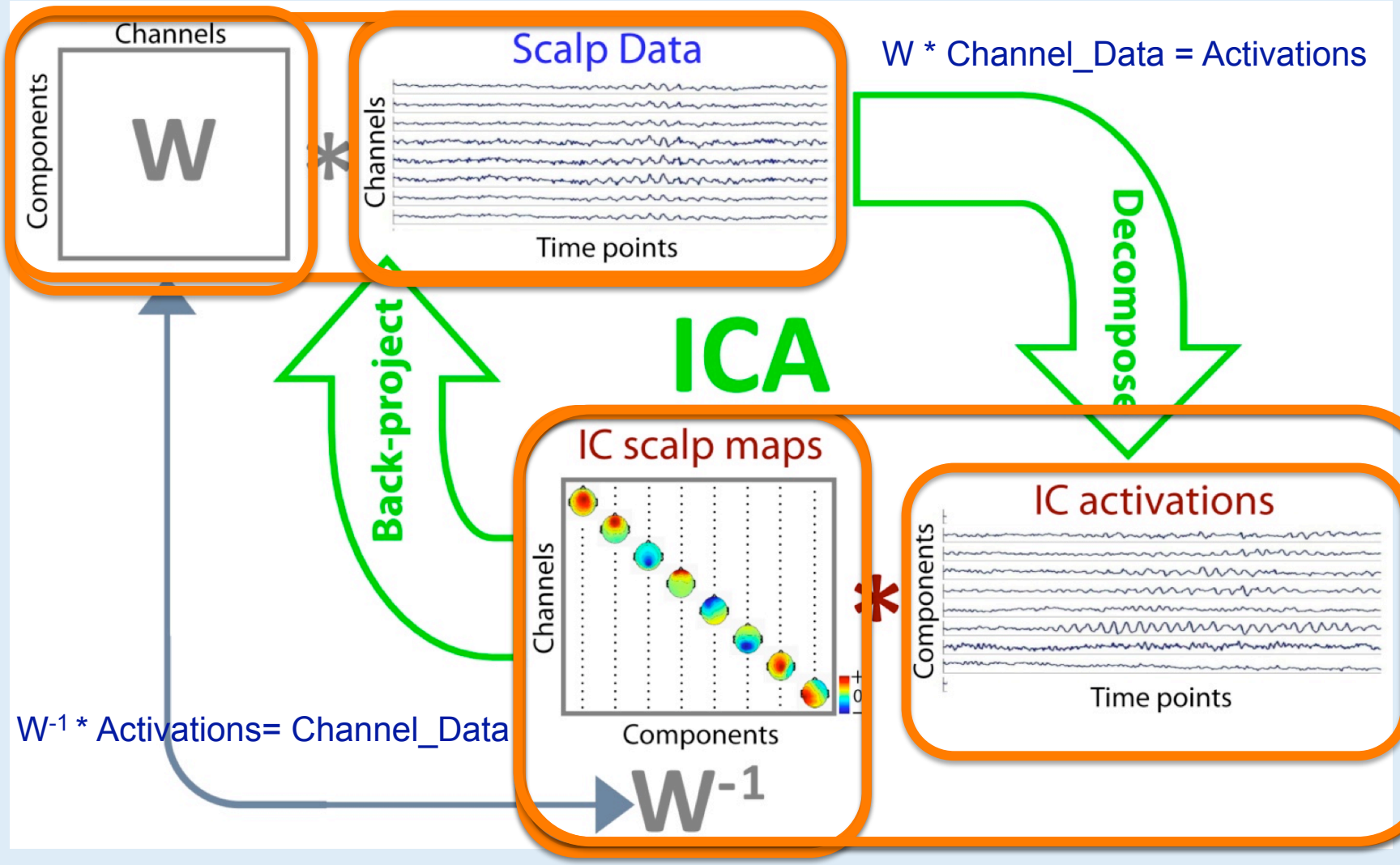
Distributed muscle / movement events





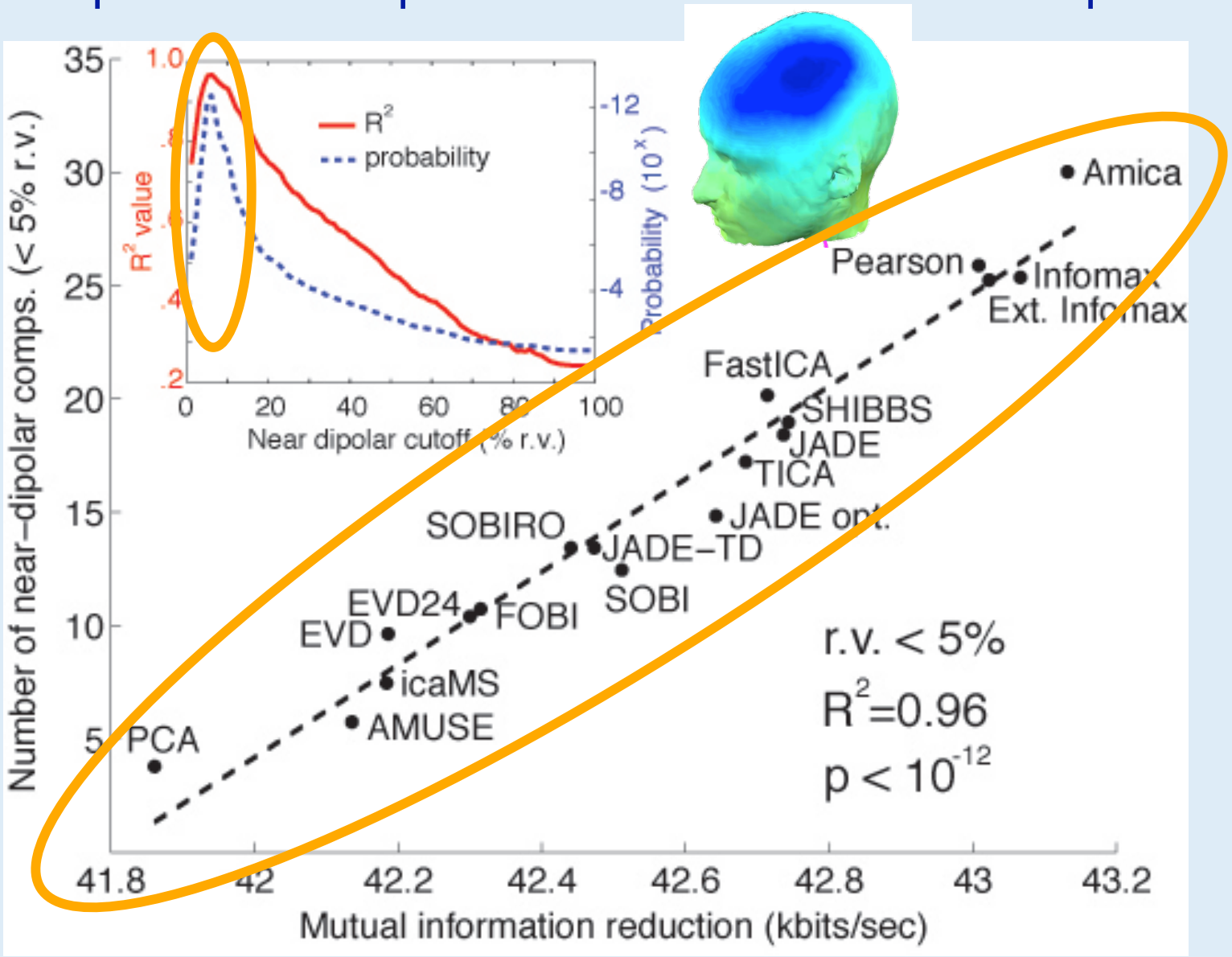
N. Bigdely & S. Makeig, 2009

ICA is a linear data decomposition method



Makeig & Onton, 2011

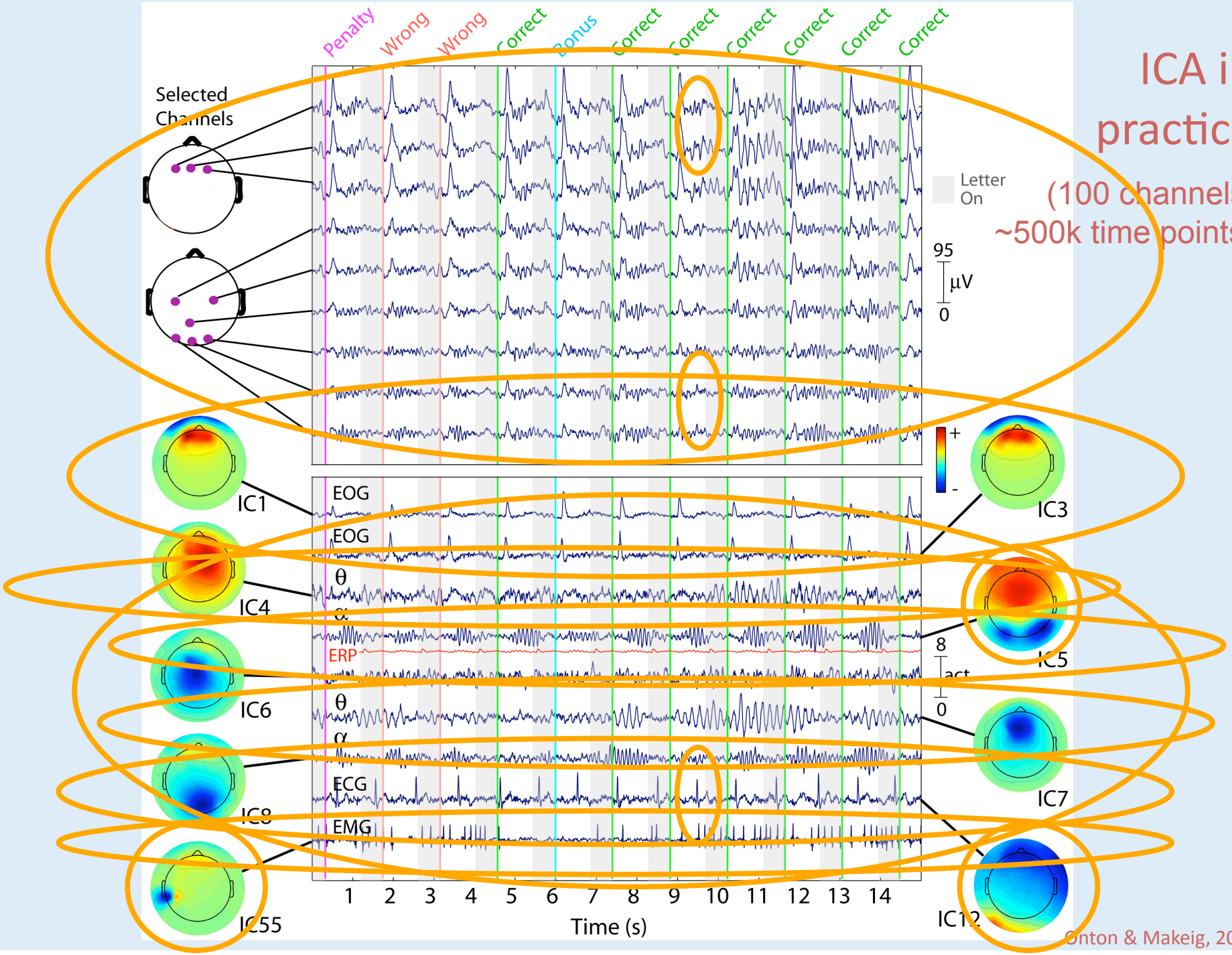
Independent Components of Human EEG are Dipolar



Delorme, Palmer, Makeig, 2011

ICA in practice

(100 channels, ~500k time points)



Onton & Makeig, 2006

Questions?