Event-Related Brain Dynamics I

Swartz Center for Computational Neuroscience

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University of California San Diego

21st EEGLAB Workshop

Santa Margherita Ligure, Italy

April, 2015

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

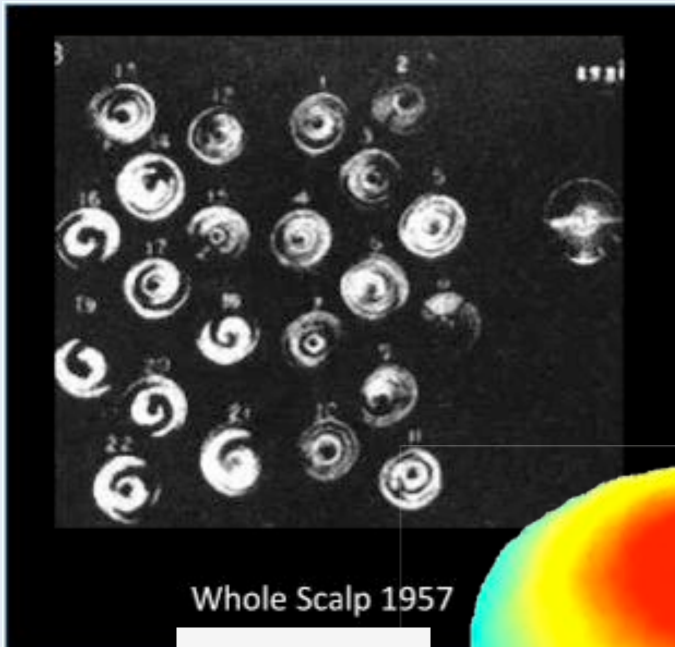
2009 ~1st commercial dry electrode EEG toys

fEEG / BMI / MoBI era ...

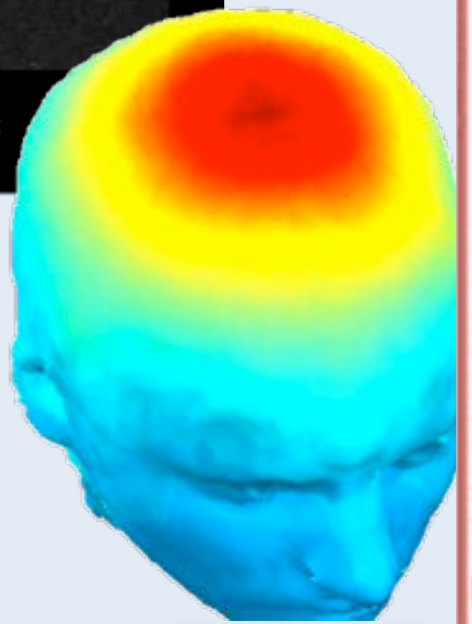
FIGURE 1-2.—Sample of the first EEG tracing taken at the Bradley Hospital, E. Providence, Rhode Island, by H. Jasper and L. Carmichael. Subject: Carl Pfaffmann. Date: July 9, 1934. Record, which shows prominent alpha rhythm of about 11.5 per second, was made with a Westinghouse, galvanometer-type, mirror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

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

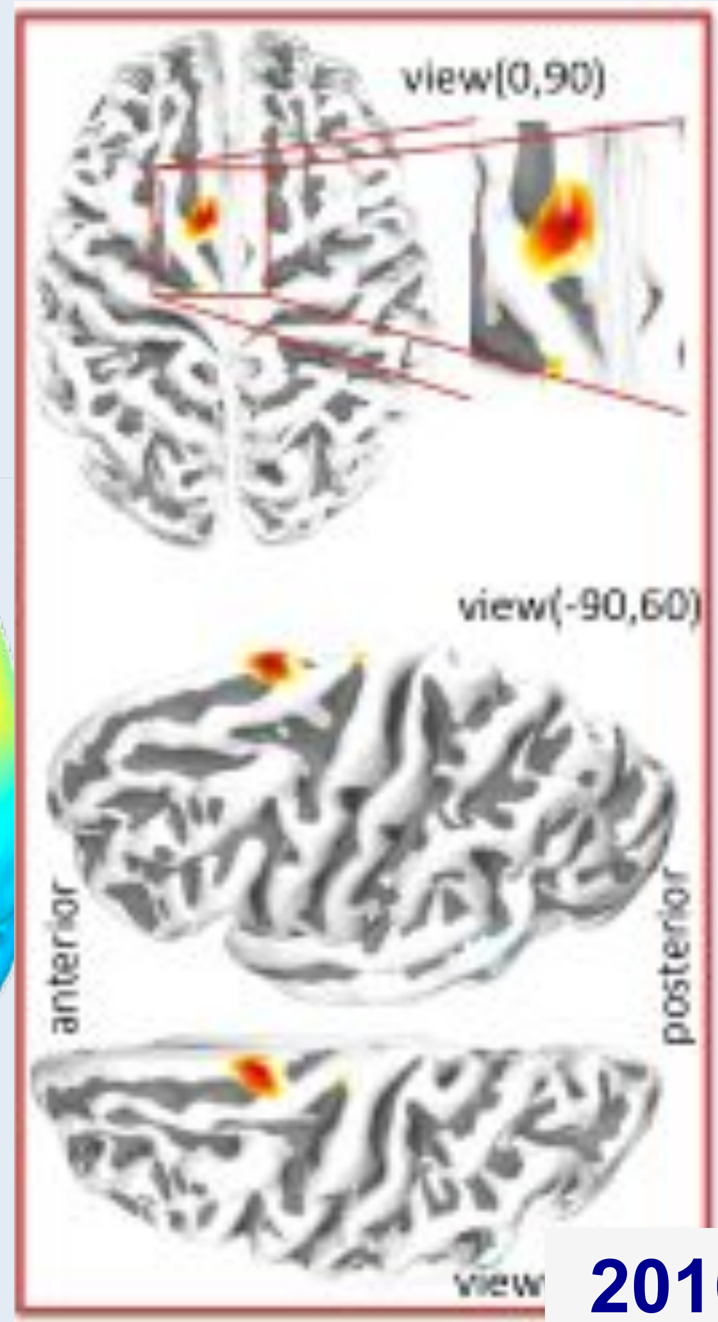
S. Makeig 2010



1957



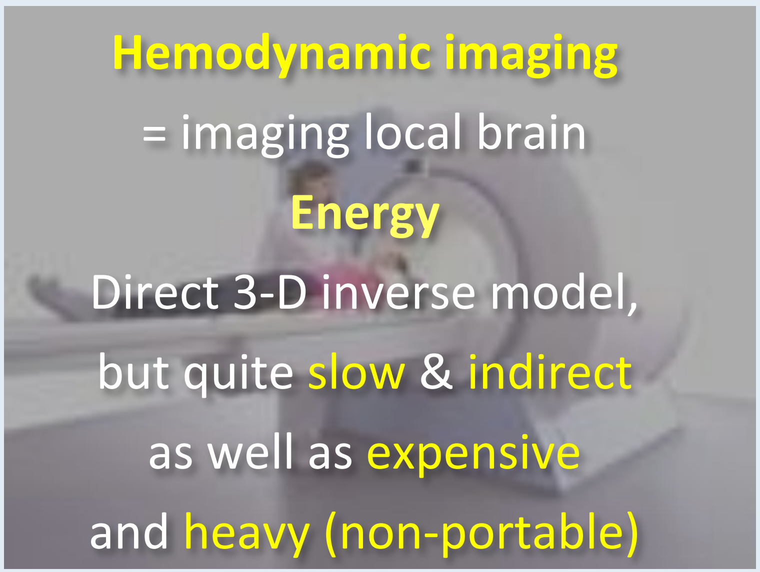
1997

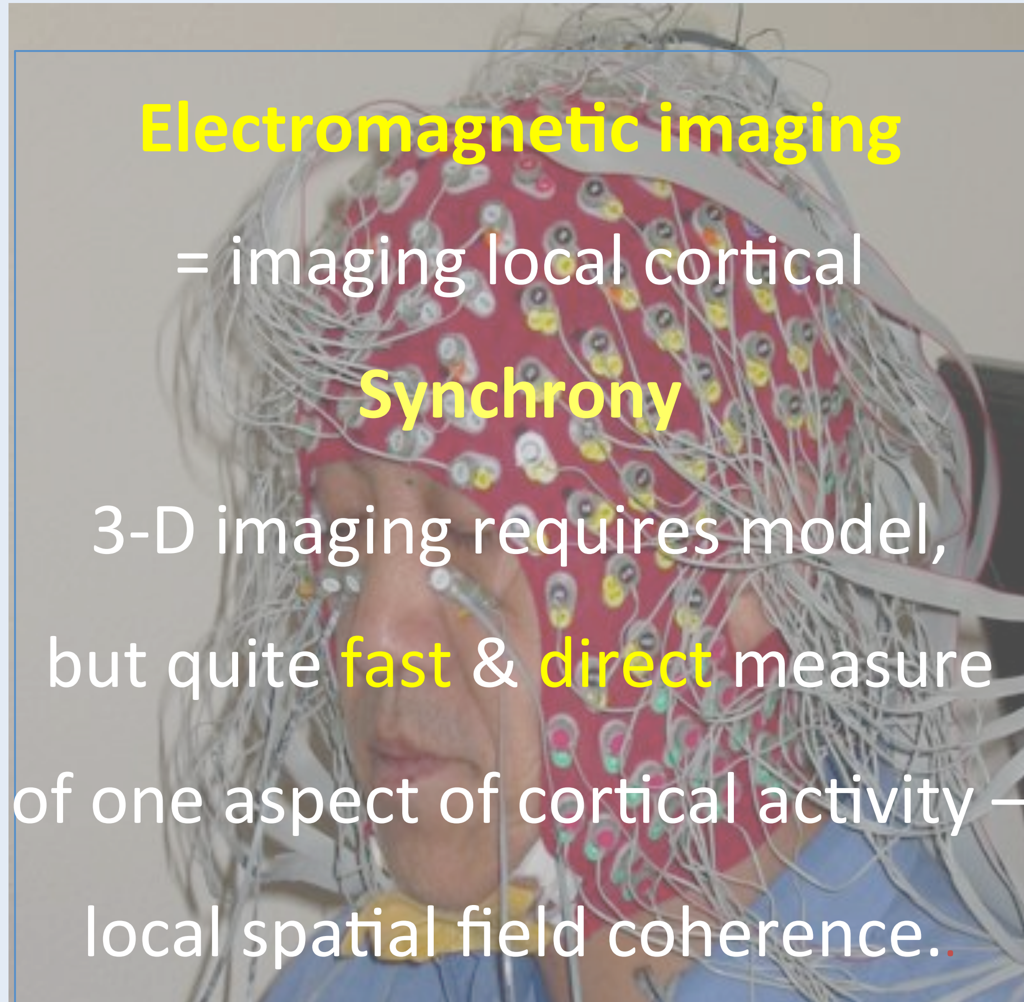


2016

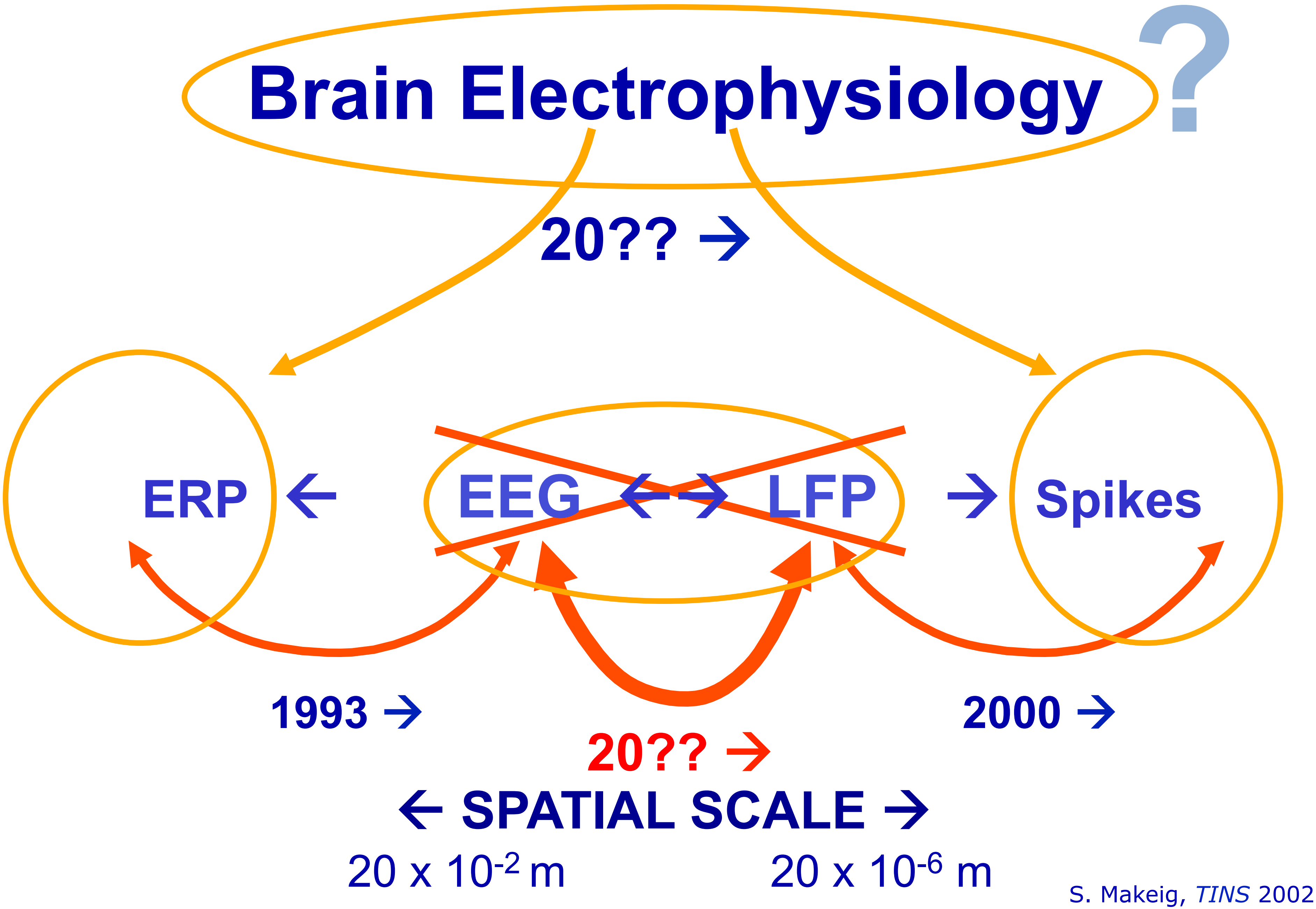
A. Akalin Acar, C. Acar & S. Makeig, 2015

Functional Brain Imaging





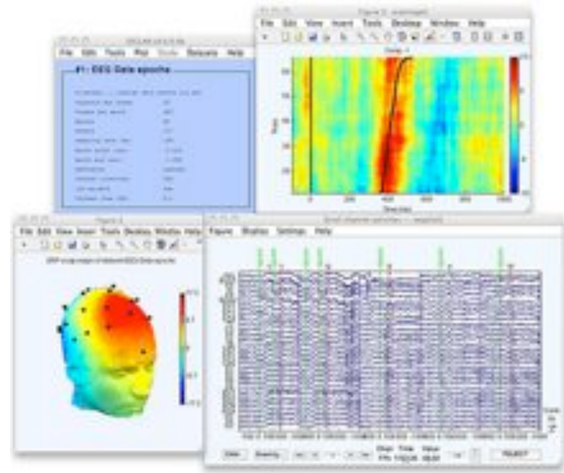
- **EEG is inexpensive**
- **EEG is well tolerated**
- **EEG is lightweight / wearable / mobile**



Brain Electrophysiology
?
20?? →
ERP ←
EEG ←→ LFP
→ Spikes
1993 →
2000 →
20?? →
← SPATIAL SCALE →
20 x 10-2 m
20 x 10-6 m
S. Makeig, *TINS* 2002

Swartz Center for Computational Neuroscience

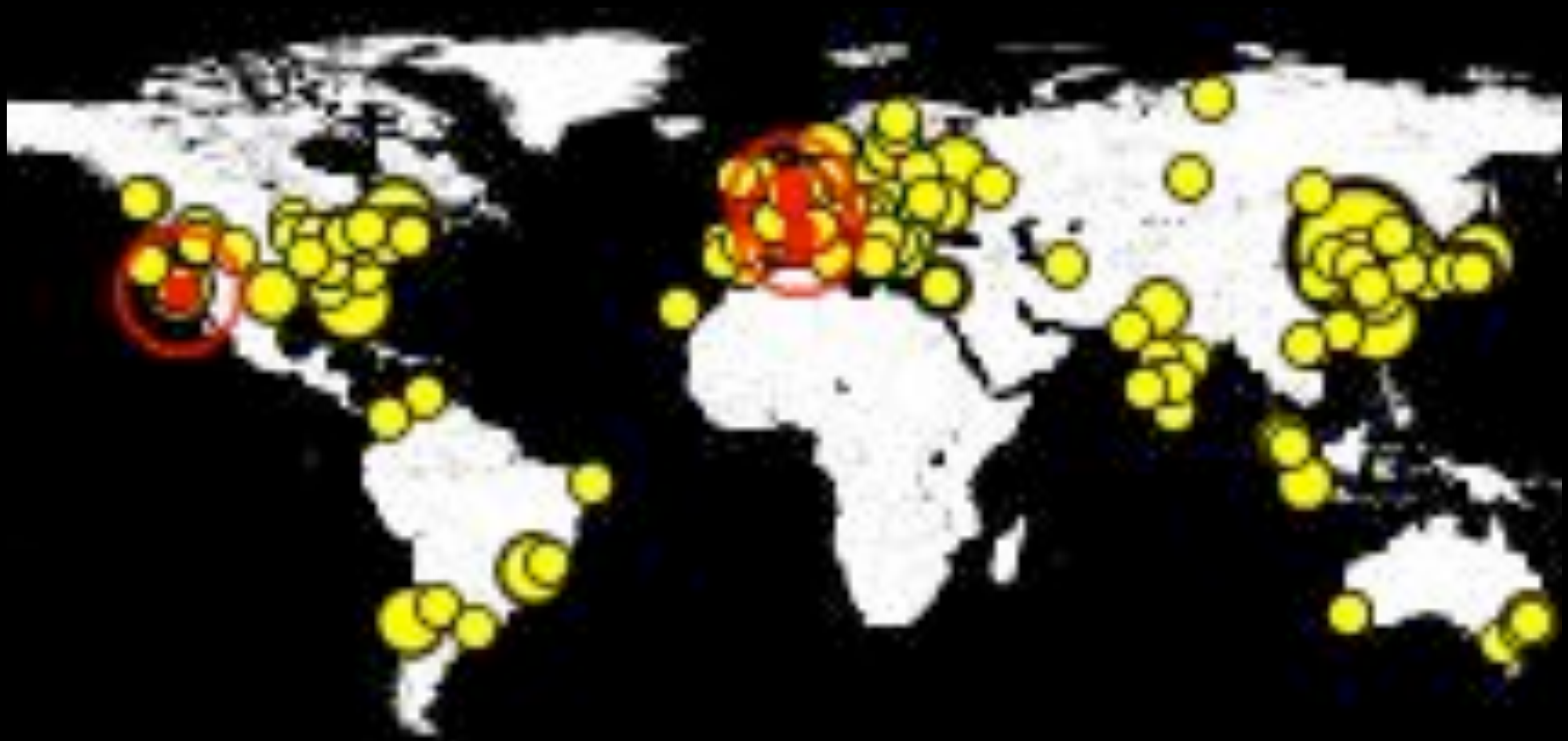
EEGLAB History



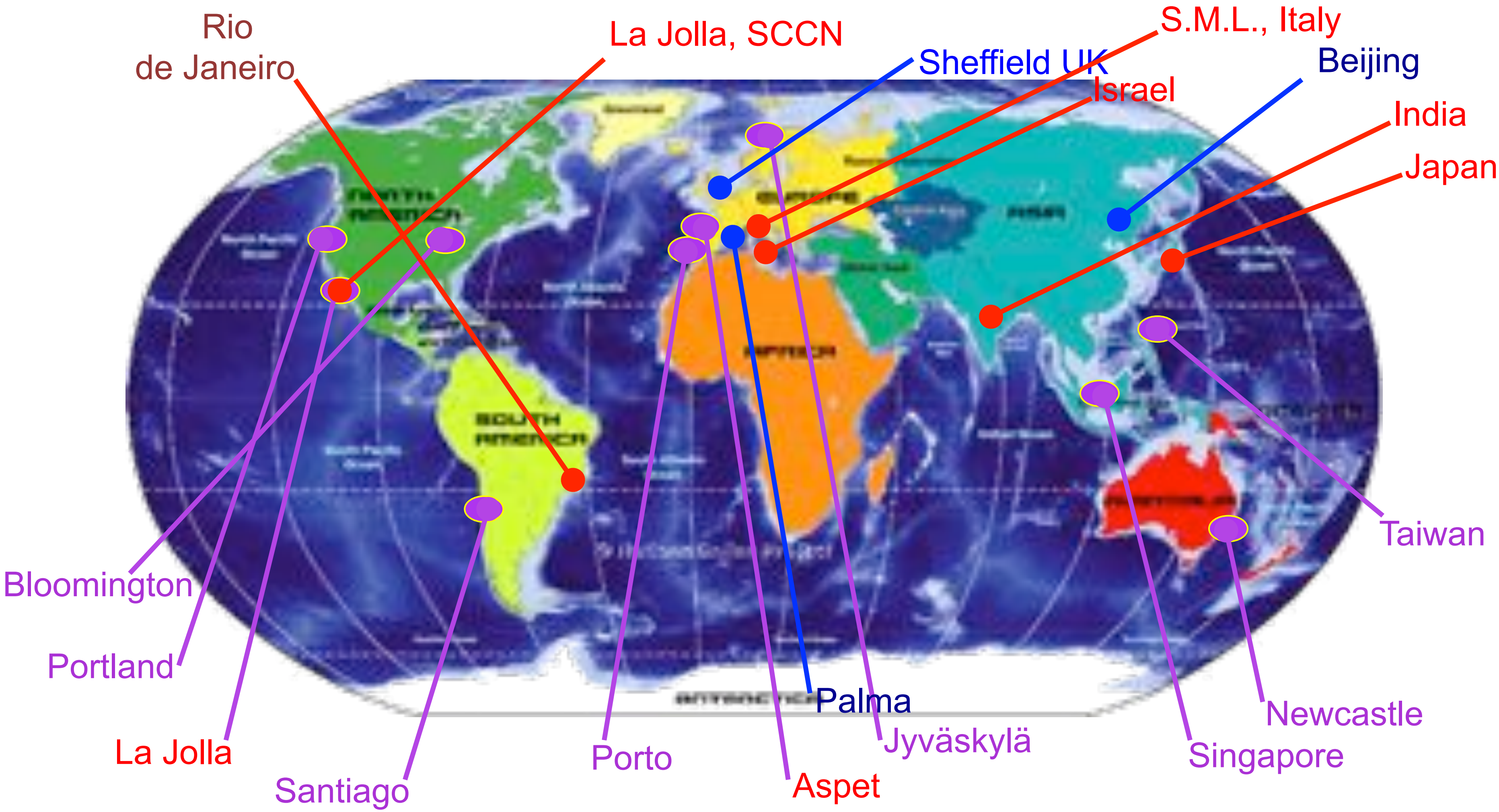
- 1993 – ERSP (Makeig)
- 1995 – Infomax ICA for EEG (Makeig, Bell, Jung, Sejnowski)
- **1997 - EEG/ICA Toolbox (cnl.salk.edu), ITC & ERC**
- 1999 - ERP-image plots (Jung & Makeig)
- 2000 – EEGLAB GUI design (Delorme)
- **2002 – 1^{st} EEGLAB (sccn.ucsd.edu)**
- **2004 - 1^{st} EEGLAB support from U.S. NIH and reference paper**
- **2006 - 1^{st} EEGLAB plug-ins, STUDY structure, and component clustering tools**
- **2009+ – New toolboxes: NFT, SIFT, BCILAB, MPT, …**
- **2011 – EEGLAB, the most widely used EEG research environment !**
- **2012 - ERICA (Experimental Real-time Interactive Control & Analysis) framework**

  for Mobile Brain/Body Imaging (MoBI) (LSL, SNAP, XDF, MoBILAB)
- **2013 – HeadIT.org online**
- **2016 – LIMO / GLM integrated**

S. Makeig 2013



EEGLAB Workshops

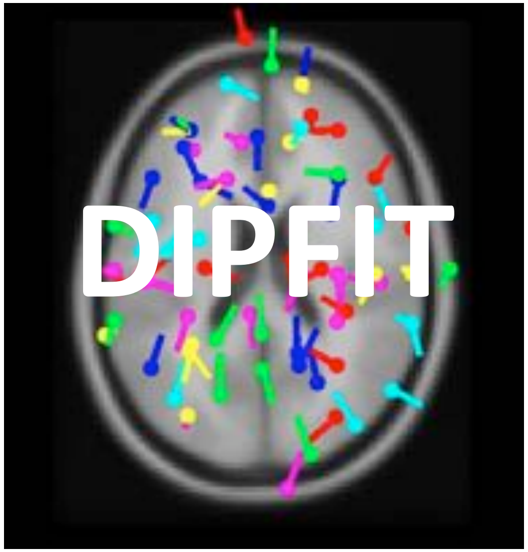


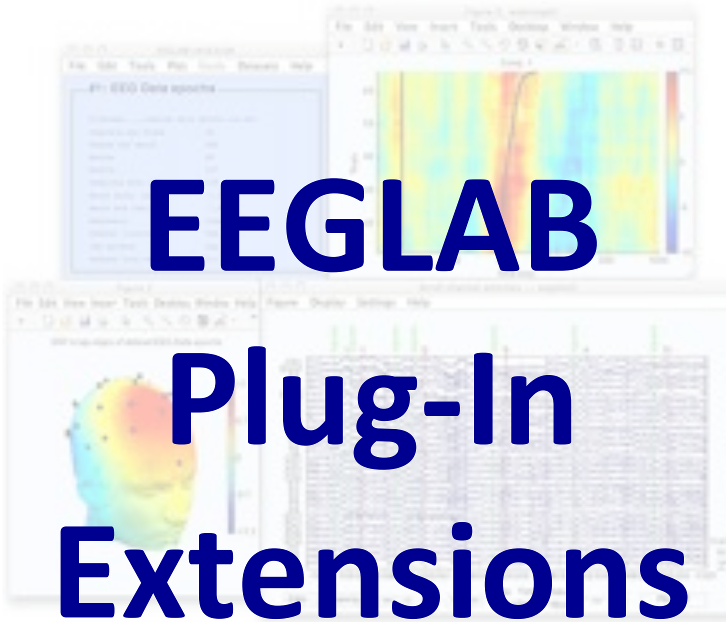
S. Makeig 2011

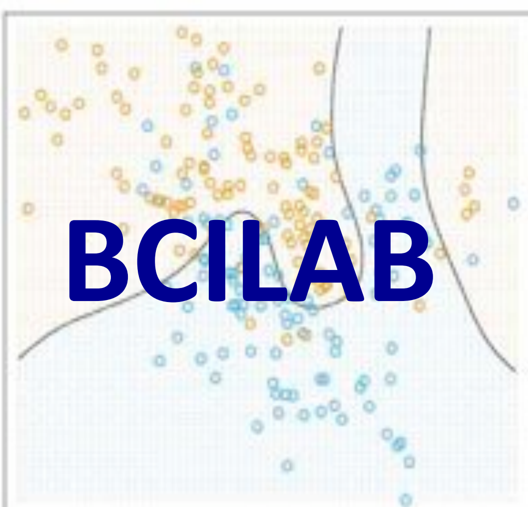
Swartz Center for Computational Neuroscience, UCSD

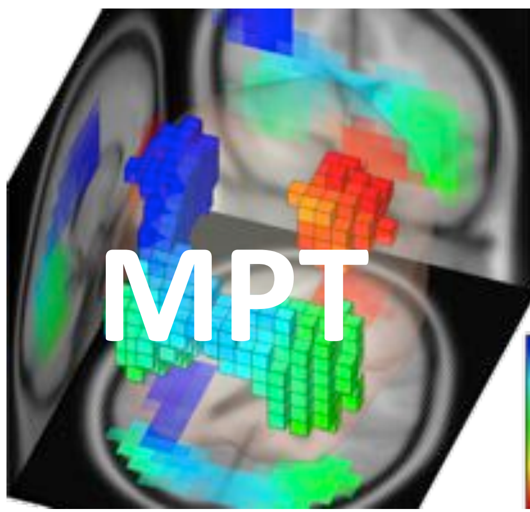
10th Anniversary SCCN Impromptu celebration 1/2/12

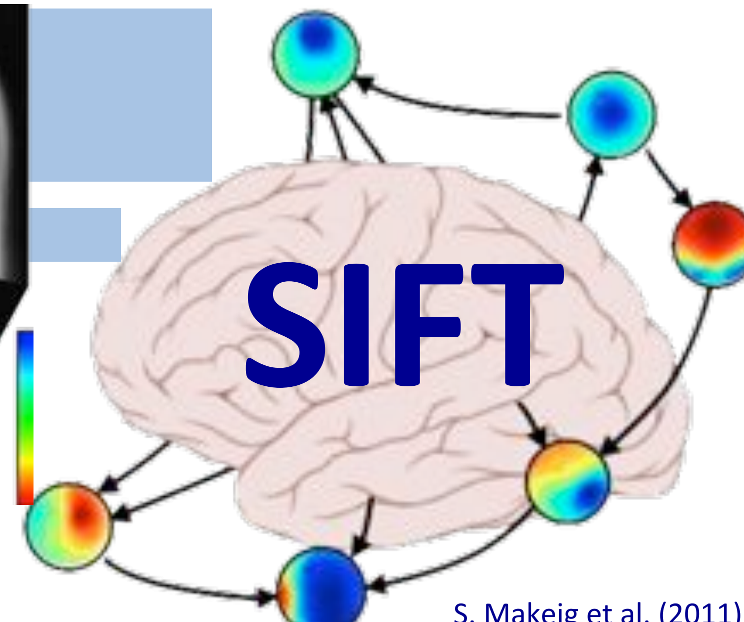
EEGLAB Plug-In Extensions











S. Makeig et al. (2011)

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 files	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	S. Pillen	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

List of data processing extensions

Plug-in name	Version	Short plug-in description	Link	Contact	Comments
rERP	0.4	Estimate overlapping ERPs using multiple regression	Download	M. Burns	User comments
LIMO	1.5	Linear MOdelling of EEG data	Download	C. Pernet	User comments
corrmap	2.02	Cluster ICA components using correlation of scalp maps	Download	S. Debener	User comments
bioelectromag	1.01	Uses Bioelectromagnetism toolbox for ERP peak detection	Download	D. Weber	User comments
VisEd	1.05	Add/Edit dataset events	Download	J. Desjardins	User comments
loreta	1.10	Export and import data to and from LORETA software	Download	A. Delorme	User comments
iirfilt	1.02	Non linear filtering using IIR filter	Download	M. Pozdin	User comments
std_envtopo	2.39	Plot STUDY ICA cluster contribution to ERP	Download	M. Miyakoshi	User comments
std_selectICsByCluster	0.10	Forward-project clustered ICs to channels (beta)	Download	M. Miyakoshi	User comments
std_dipoleDensity	0.23	Plot STUDY ICA cluster dipole density (beta)	Download	M. Miyakoshi	User comments
std_ErpCalc	0.11	Test and visualize simple effects on ERP (beta)	Download	M. Miyakoshi	User comments
pvaftopo	0.10	Plot topography of percent variance accounted for (beta)	Download	M. Miyakoshi	User comments
trimOutlier	0.16	Trim outlier channels and datapoints interactively (beta)	Download	M. Miyakoshi	User comments
clean_rawdata	0.31	Cleans continuous data using Artifact Subspace Reconstruction	Download	Miyakoshi and Kothe	User comments
AFfitStudio	0.10	Cleans spiky artifacts using AFfit (beta)	Download	Miyakoshi and Mullen	User comments
Mutual_Info_Clustering	1.00	Group single dataset ICA components by Mutual Information	Download	N. Bigdely	User comments
mass_univ	130502	Mass Univariate ERP Toolbox	Download	D. Groppe	User comments
REGICA	1.00	ICA regression based EOG removal	Download	M. Klados	User comments
MARA	1.1	Multiple Artifact Rejection Algorithm	Download	I. Winkler	User comments
firfilt	1.6.1	Routines for designing linear filters	Download	A. Widmann	User comments
PACT	0.17	Computes phase-amplitude coupling for continuous data	Download	M. Miyakoshi	User comments
fMRIb	2.00	Remove fMRI artifacts from EEG	Download	J. Dien & R. Niazy	User comments
SIFT	1.33	Analysis and visualization of multivariate connectivity	Download	T. Mullen	User comments
AAR	131130	ICA-based Automatic Artifact Removal	Download	G. Gomez-Herrero	User comments
Adjust	1.1	Automatic Detector - Joint Use of Spatial and Temporal features	Download	Adjust Support	User comments
Cleanline	1.02	Removes sinusoidal artifacts (line noise)	Download	T. Mullen	User comments
Fieldtrip-lite	Daily	Adds source localization and statistics tools to EEGLAB	Download	R. Oostenveld	User comments
EYE-EEG	0.41	Open source MATLAB tool for simultaneous eye tracking & EEG	Download	O. Dimigen	User comments
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]


Who
am I?

Embodied Agency

Brain processes

have evolved and function

*to optimize the **outcome***

*of our **behavior –***

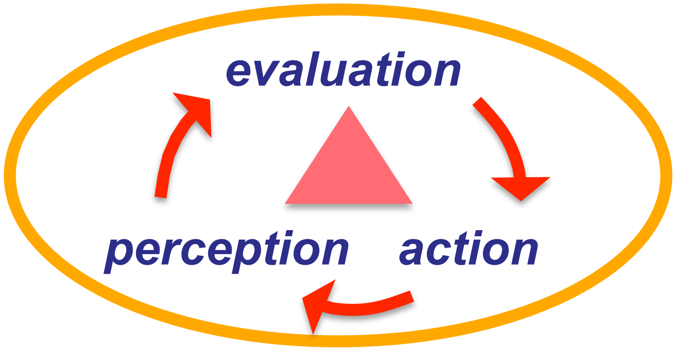
which the brain organizes

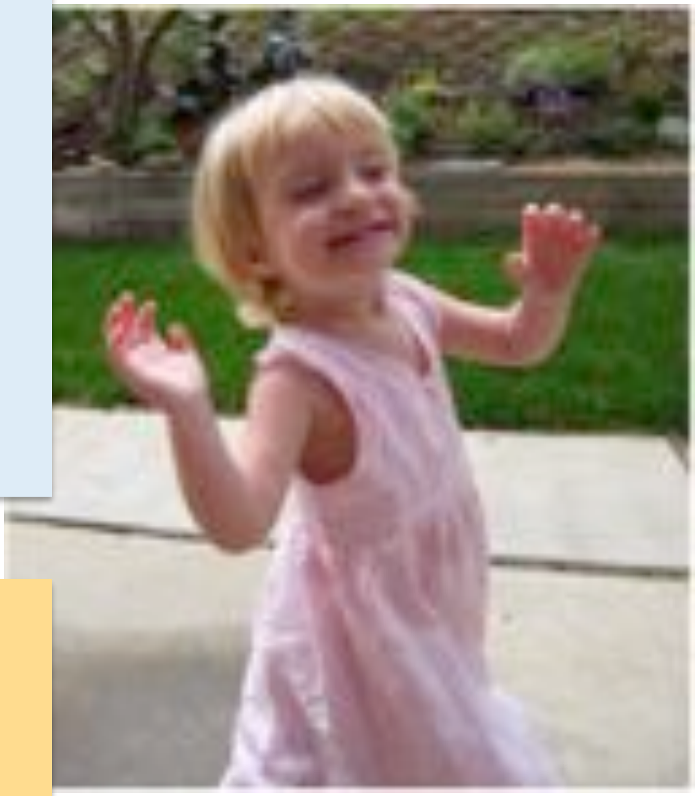
in response to

perceived challenges

***and opportunities*.**

Brains meet the challenge of the moment!





S. Makeig 2011

*Brain imaging **natural cognition** -- actions & **interactions***

Imaging Human Agency

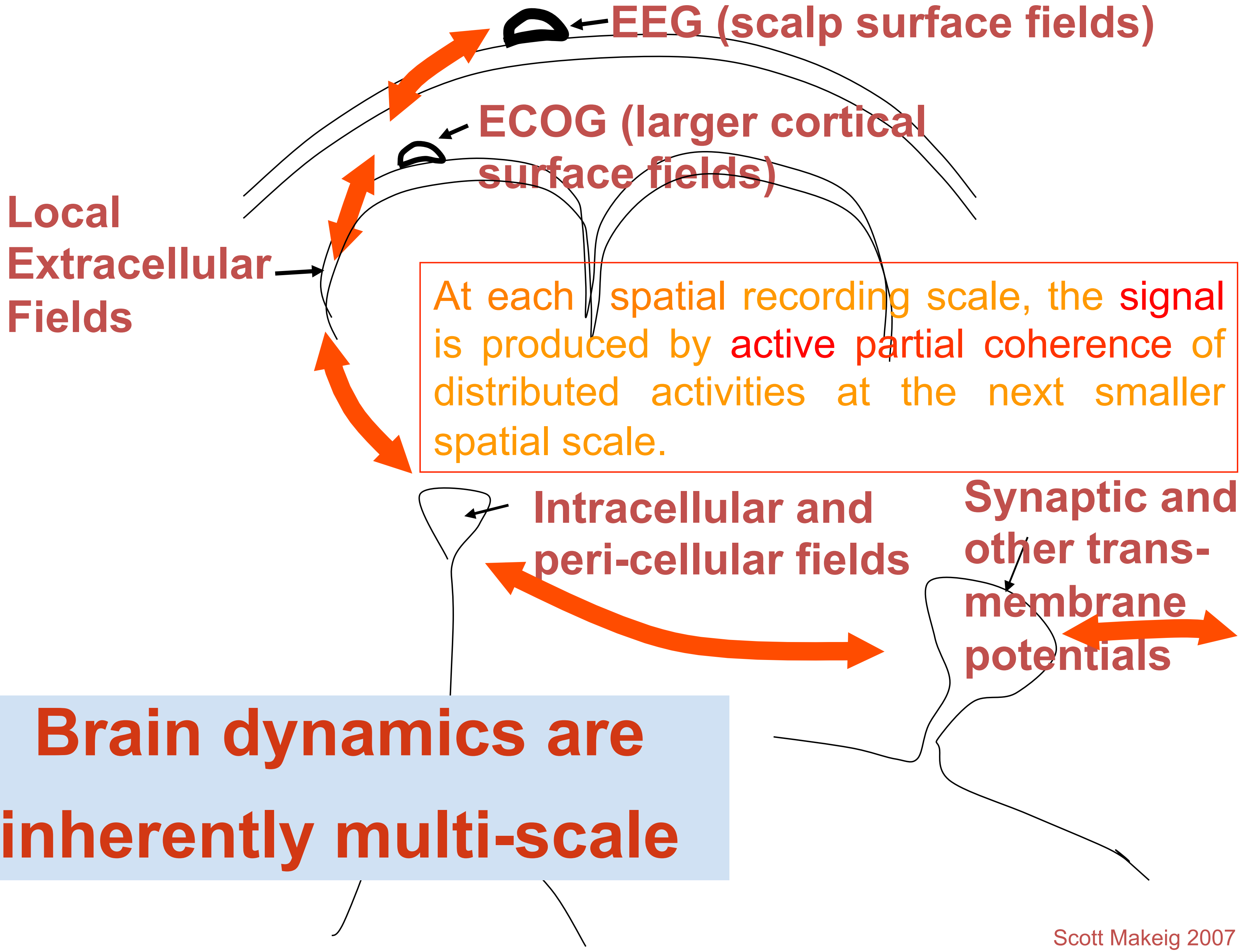
What is EEG?

- 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?**

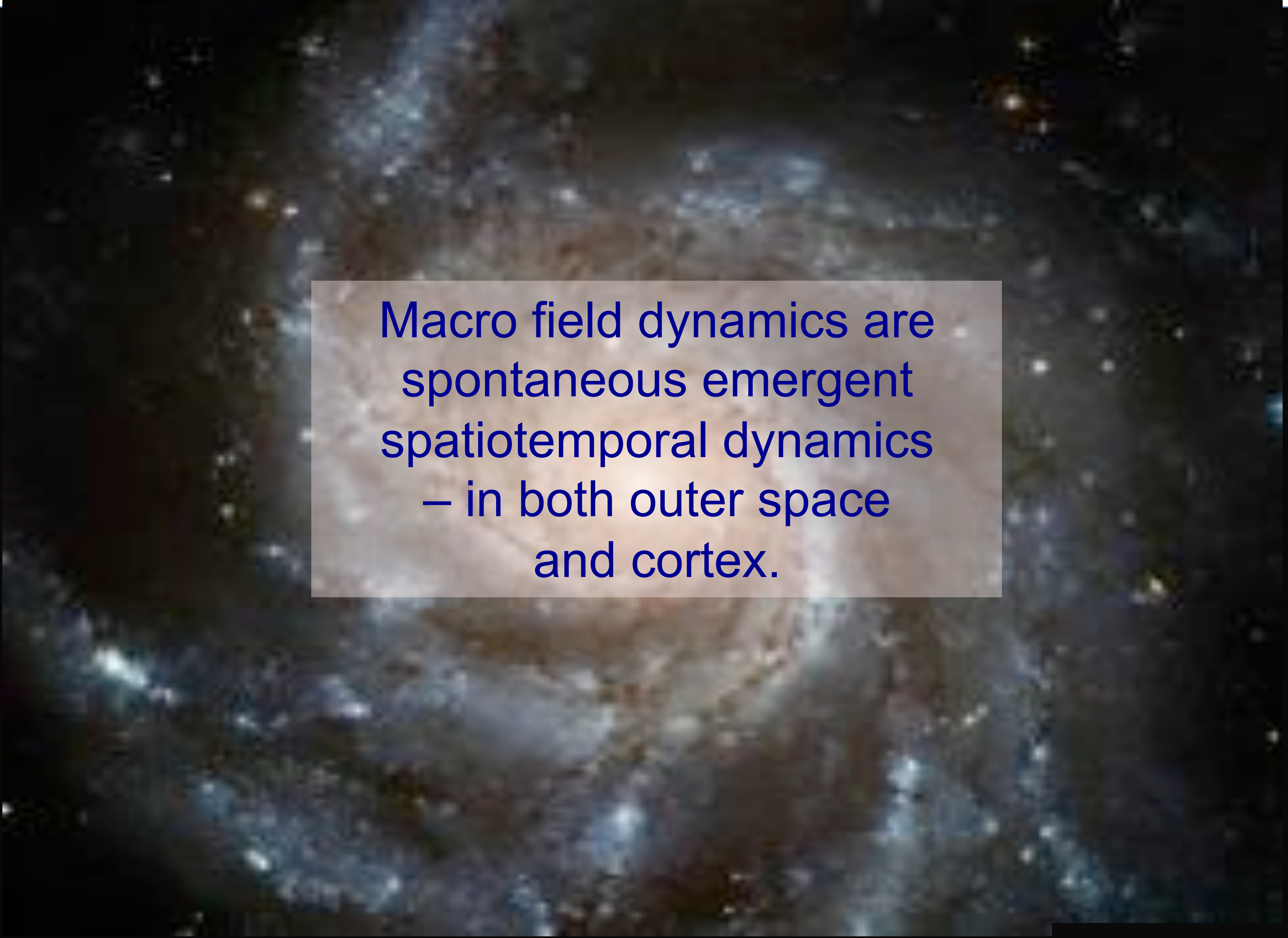
Cloud art: Berndnaut Smilde

Brain dynamics are inherently multi-scale



At each spatial recording scale, the signal is produced by active partial coherence of distributed activities at the next smaller spatial scale.

Scott Makeig 2007

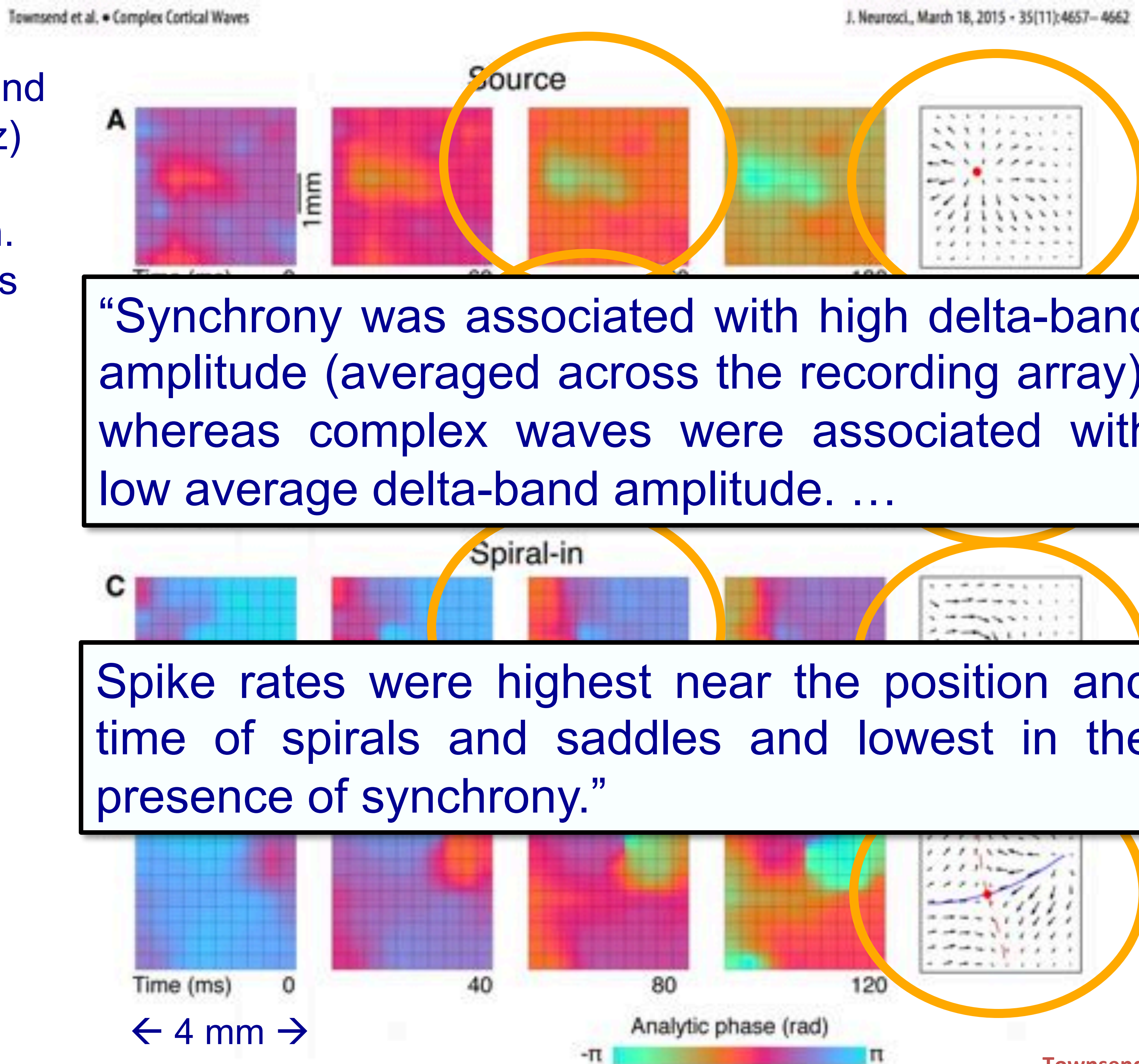

Macro field dynamics are
spontaneous emergent
spatiotemporal dynamics
– in both outer space
and cortex.

Phase cones (Freeman)

Avalanches (Plenz)

Local Cortical Synchronies
are
Effective EEG Sources

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



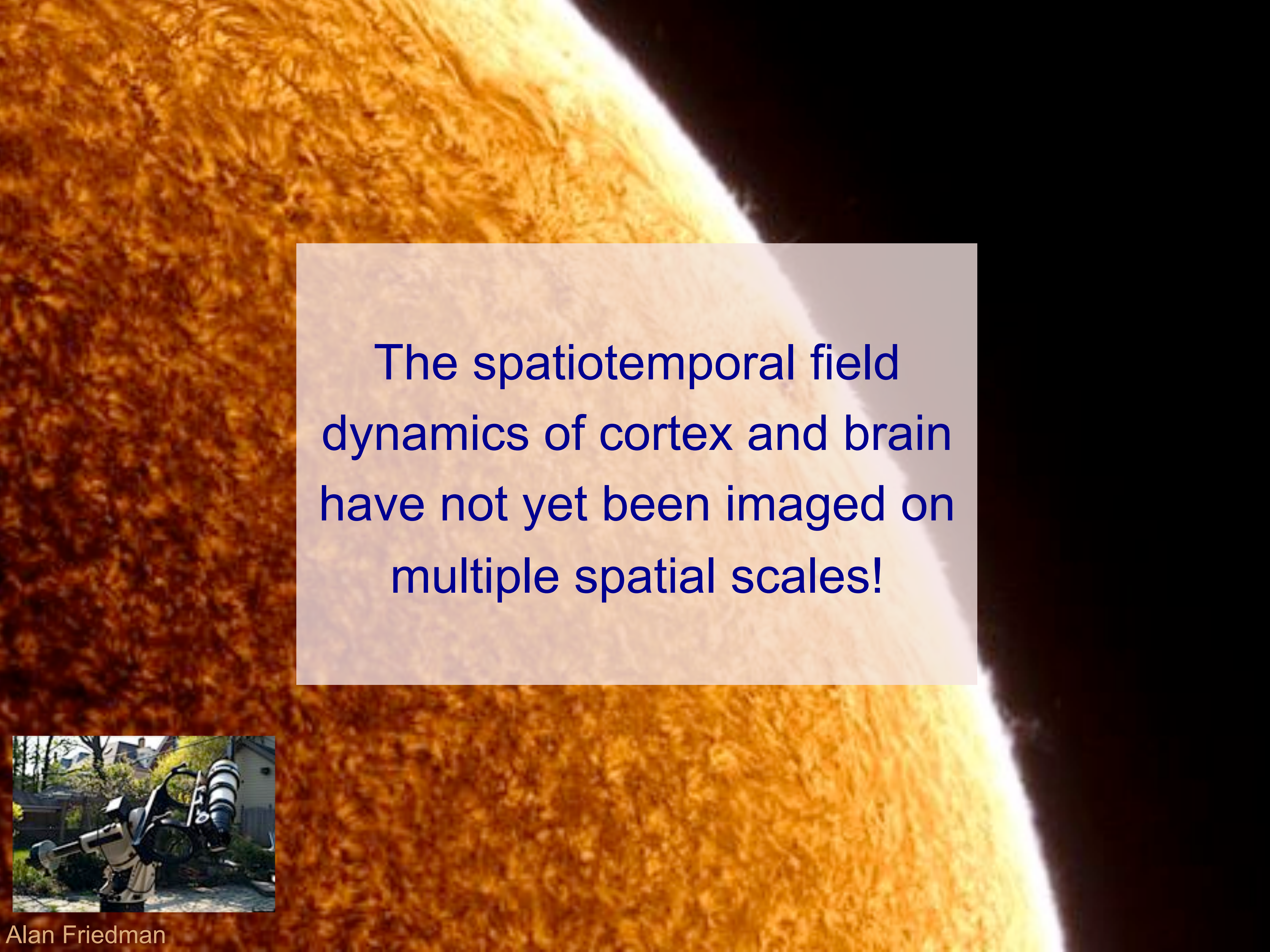
"Synchrony was associated with high delta-band amplitude (averaged across the recording array), whereas complex waves were associated with low average delta-band amplitude. …

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

Simple patterns

Complex patterns

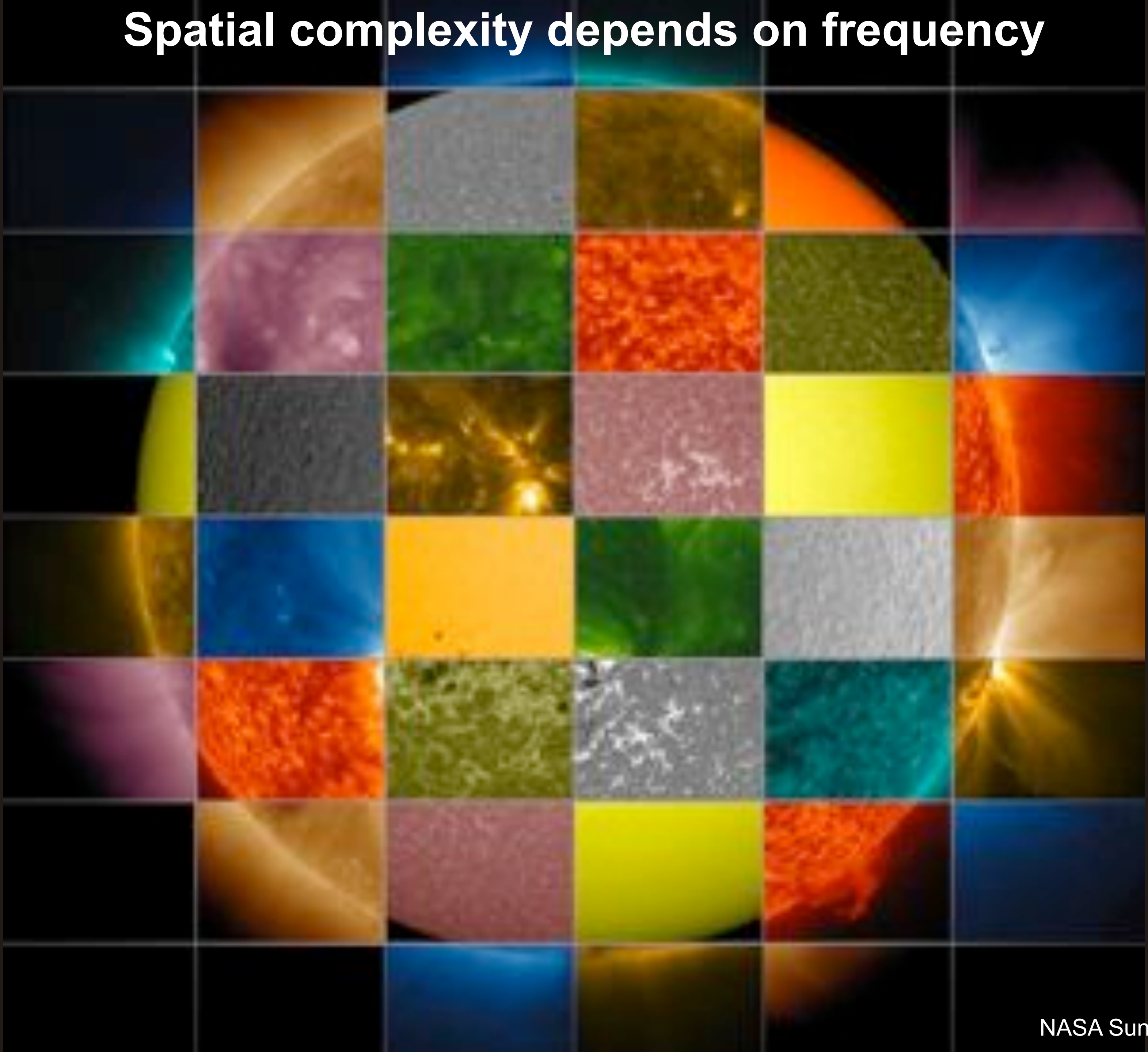
Townsend et al., 2015



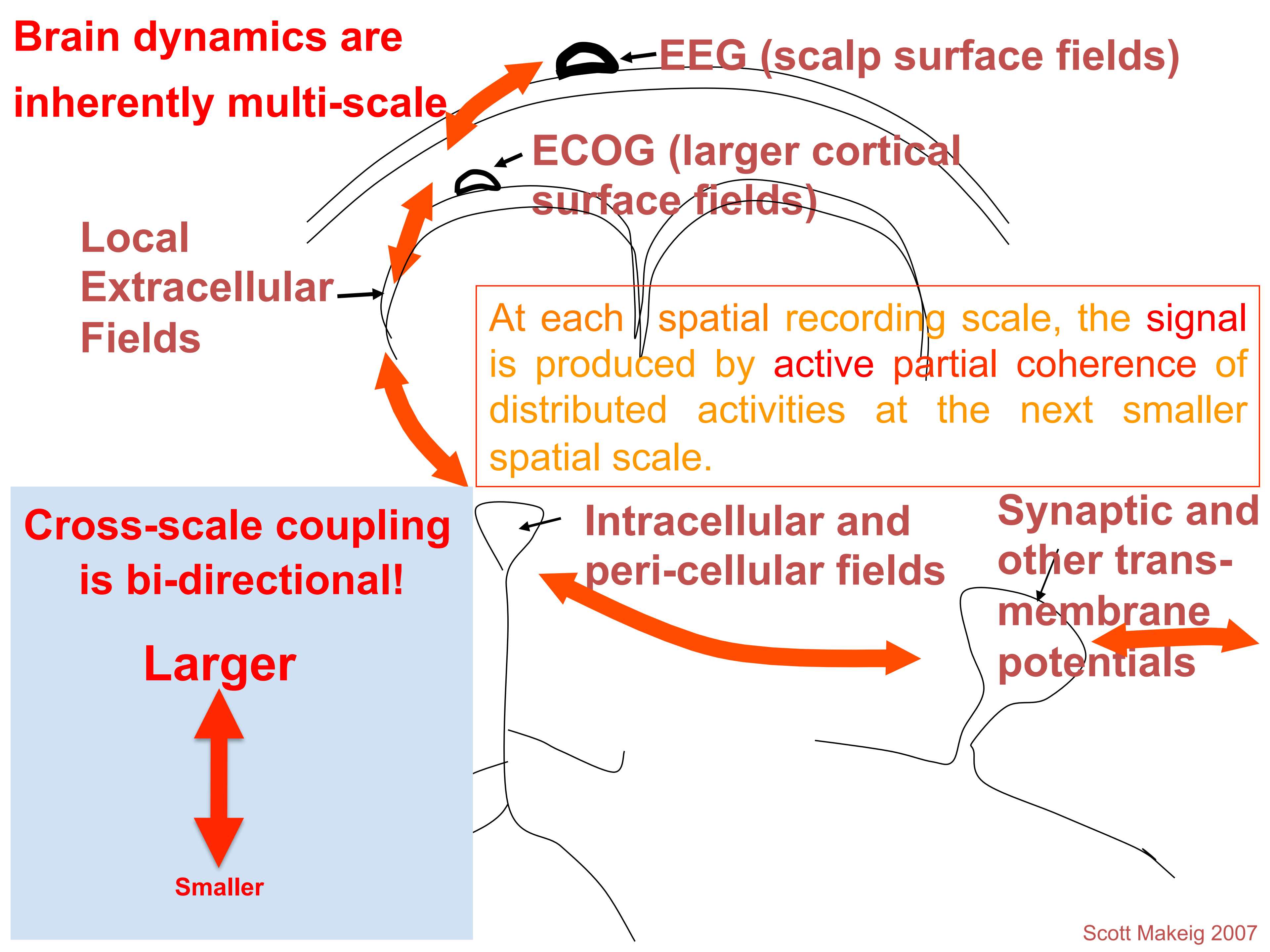
The spatiotemporal field dynamics of cortex and brain have not yet been imaged on multiple spatial scales!

Alan Friedman

Spatial complexity depends on frequency

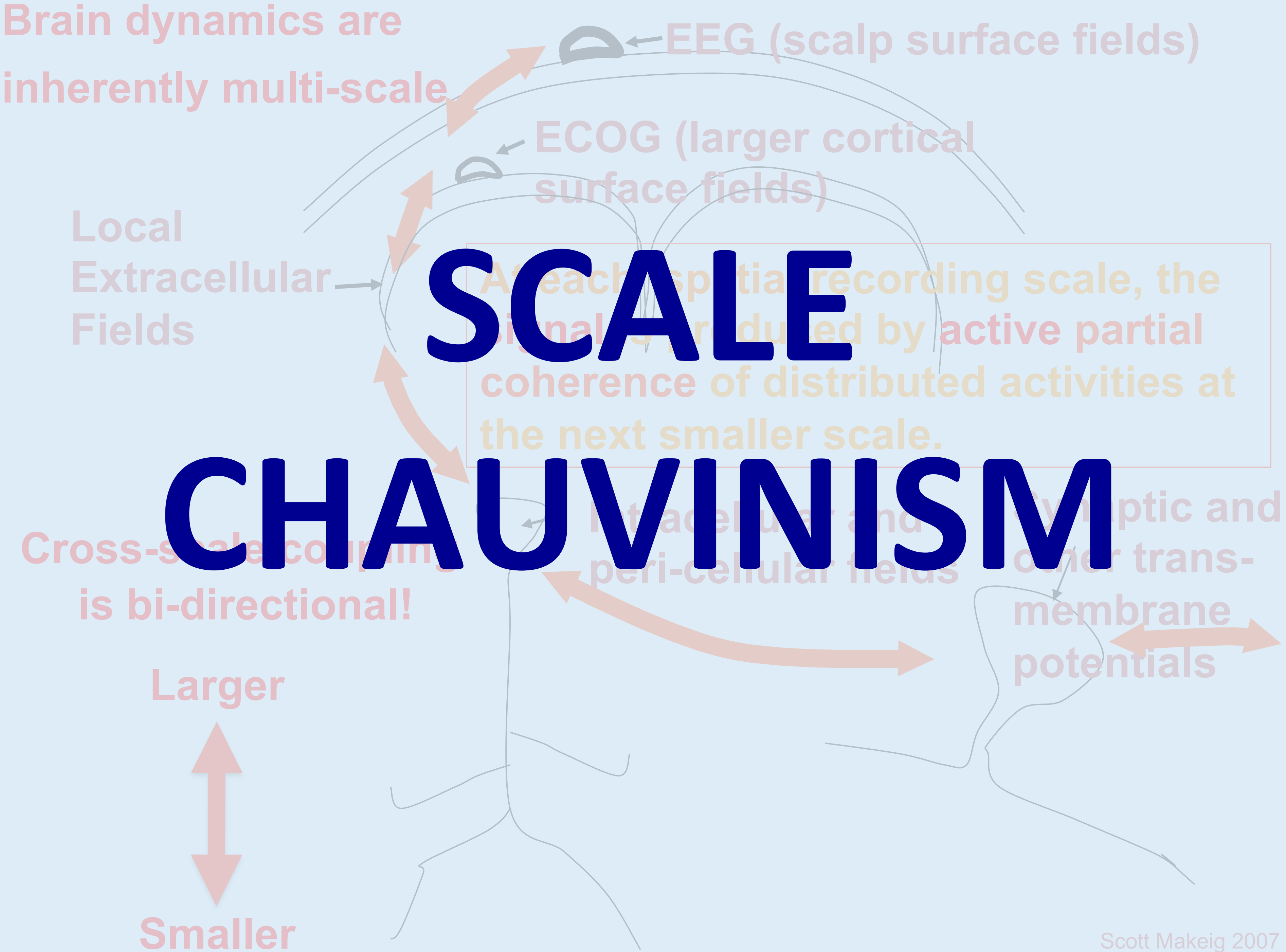


NASA Sun Observatory



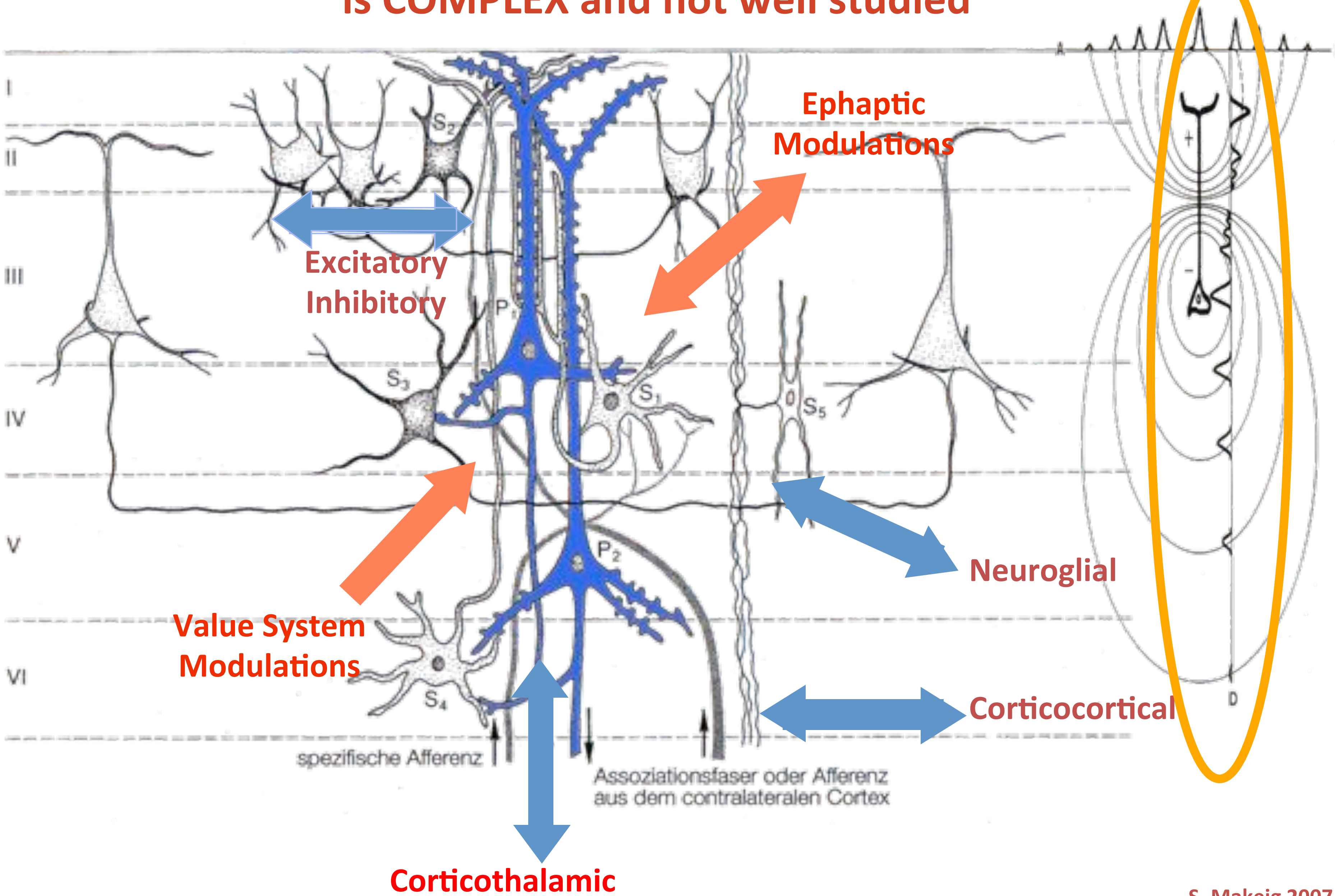
Brain dynamics are inherently multi-scale
EEG (scalp surface fields)
ECOG (larger cortical surface fields)
Local Extracellular Fields
At each spatial recording scale, the signal is produced by active partial coherence of distributed activities at the next smaller spatial scale.
Cross-scale coupling is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

SCALE CHAUVINISM



Scott Makeig 2007

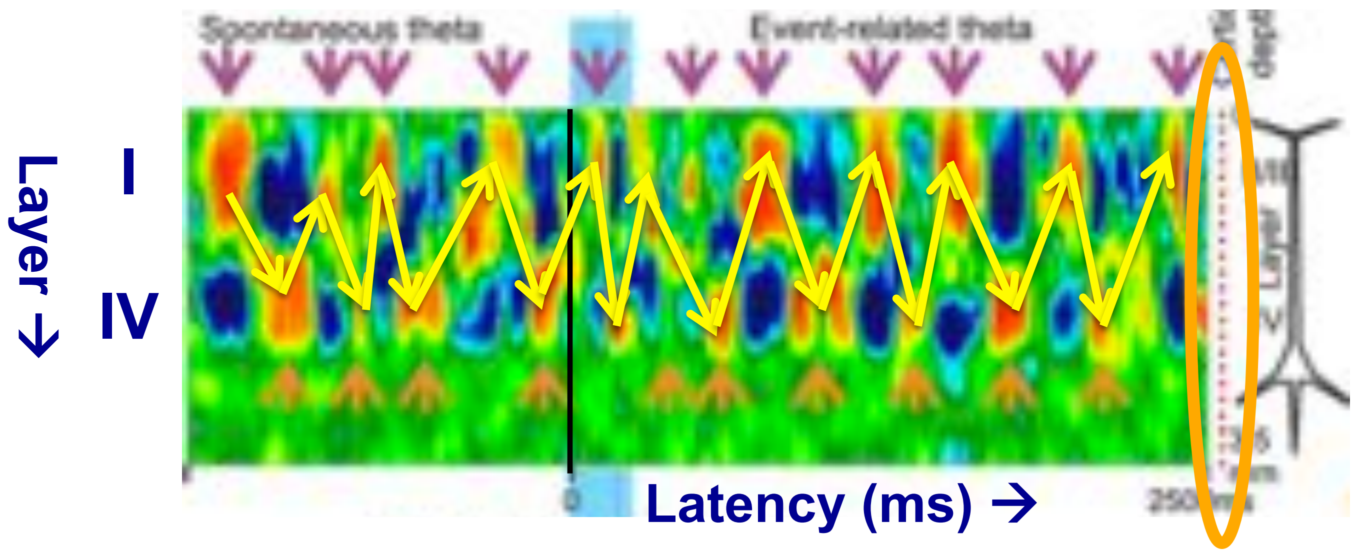
The generation and modulation of EEG is COMPLEX and not well studied



S. Makeig 2007

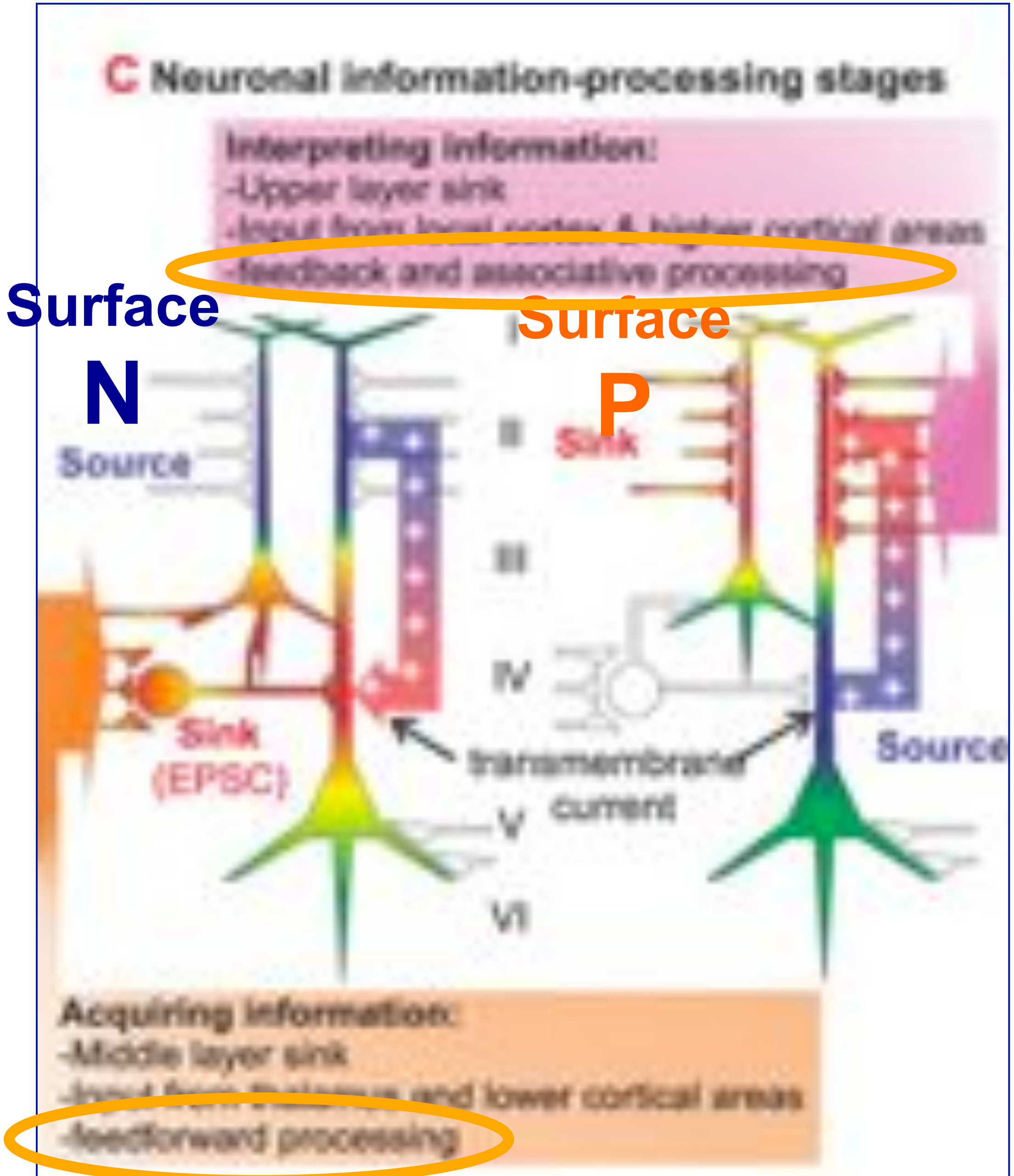
In Cortex: Up ≠ Down
and +μV ≠ -μV

Cortical surface ⬆ Up



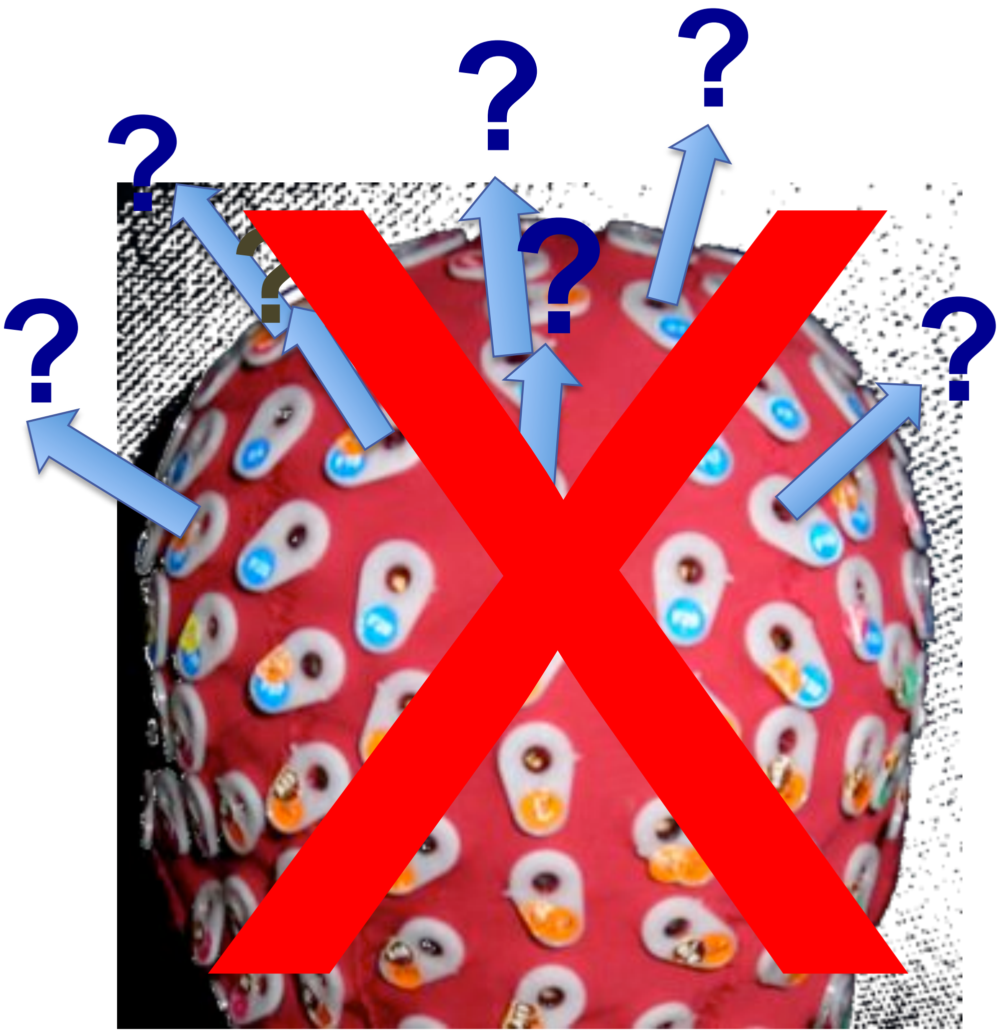
Thalamus
Down
⬇

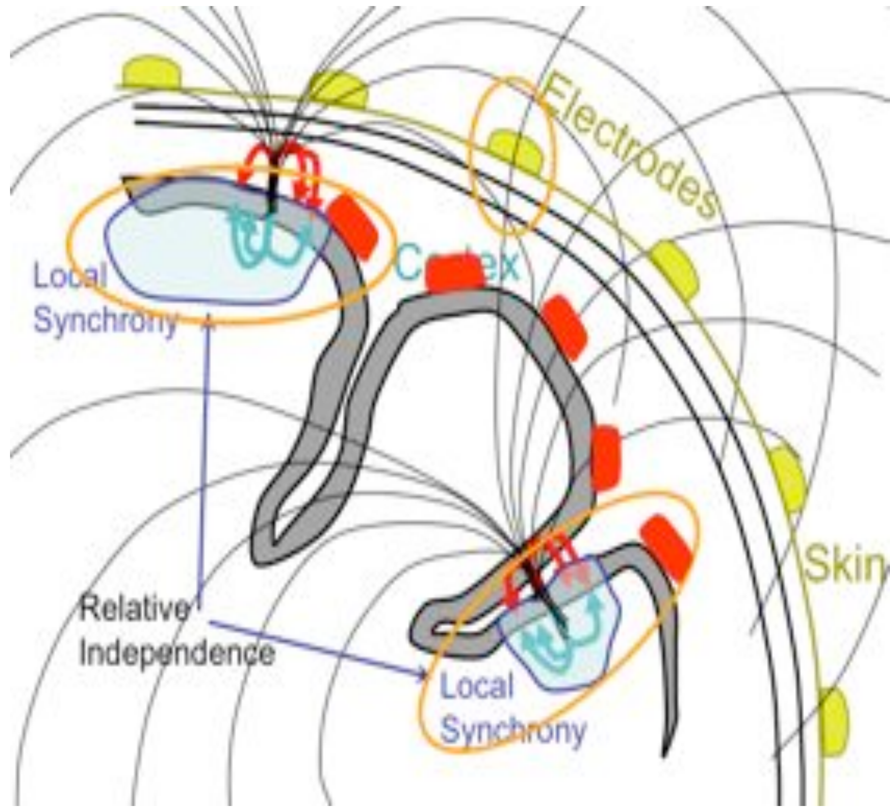
E. Halgren et al., 2015



From E. Halgren et al., 2015 cf. T. Elbert, ~1990 Slide: S. Makeig, 2016

Naïve 2-D interpretation of EEG signals?

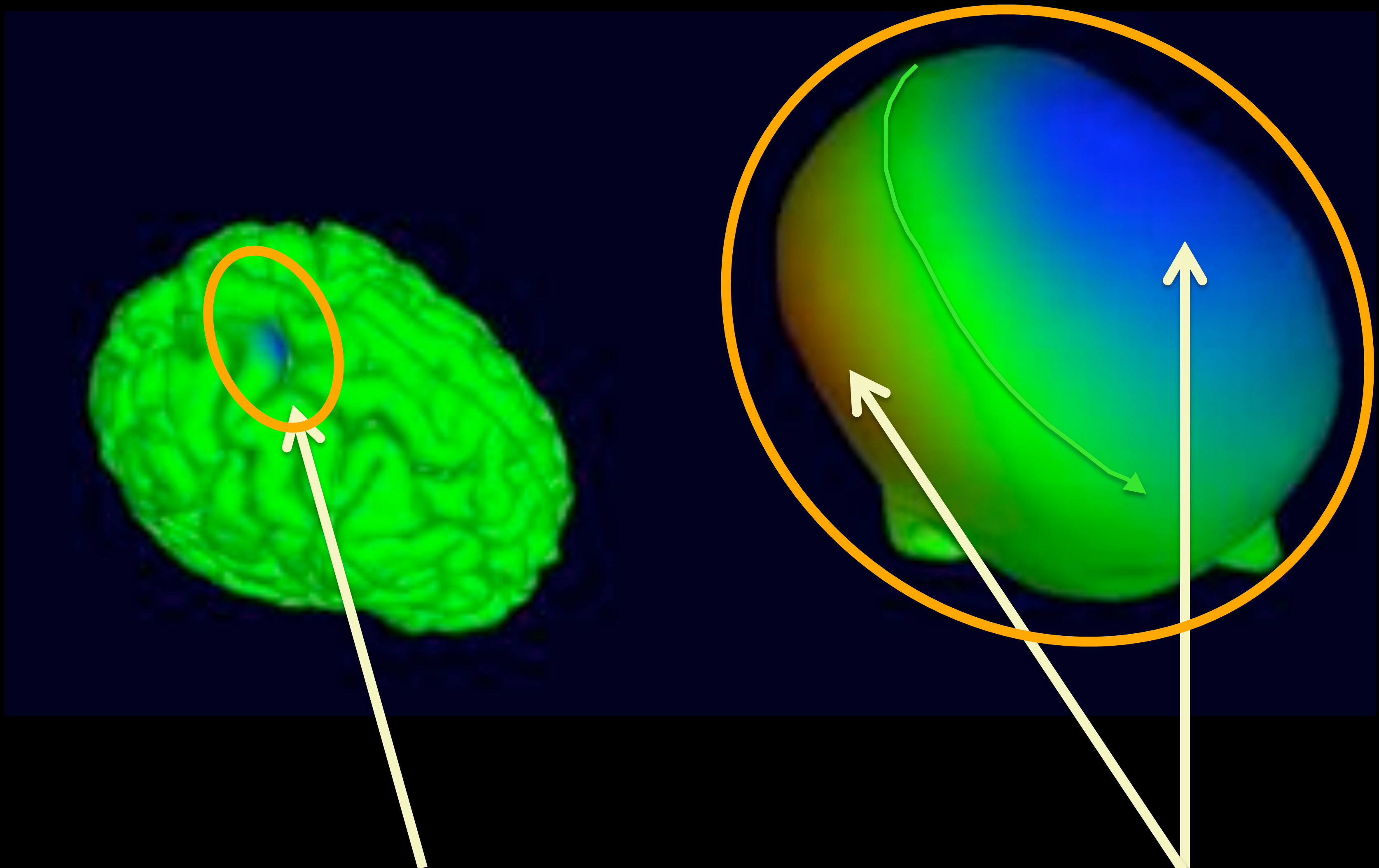




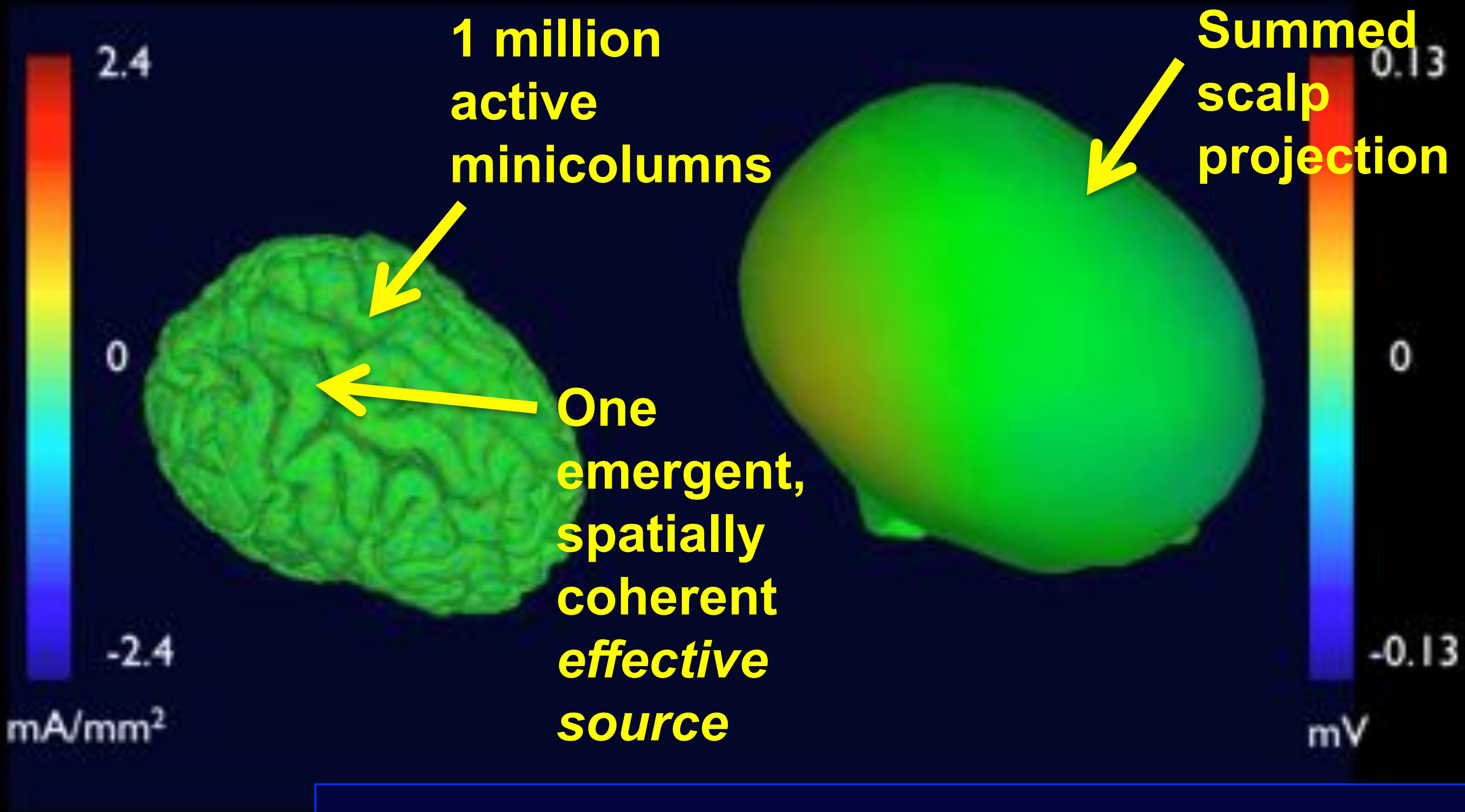
Cortical EEG signal projection patterns as point processes

Cortical source current volume conduction patterns

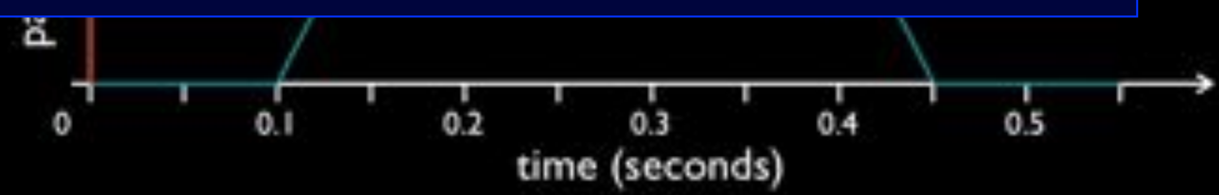
The very broad EEG point-spread function



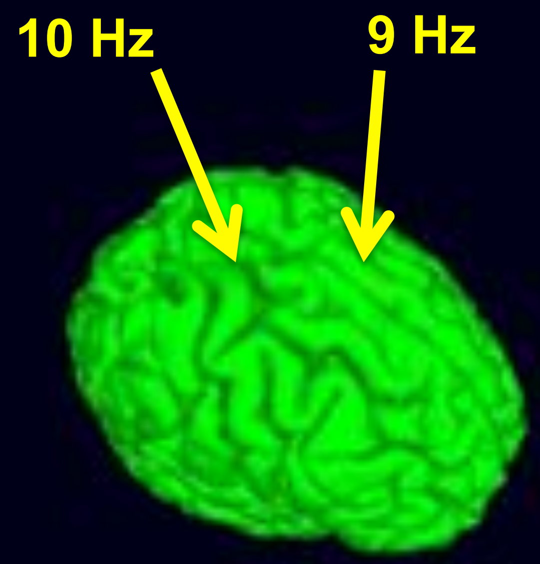
Akalin Acar & Makeig 2010



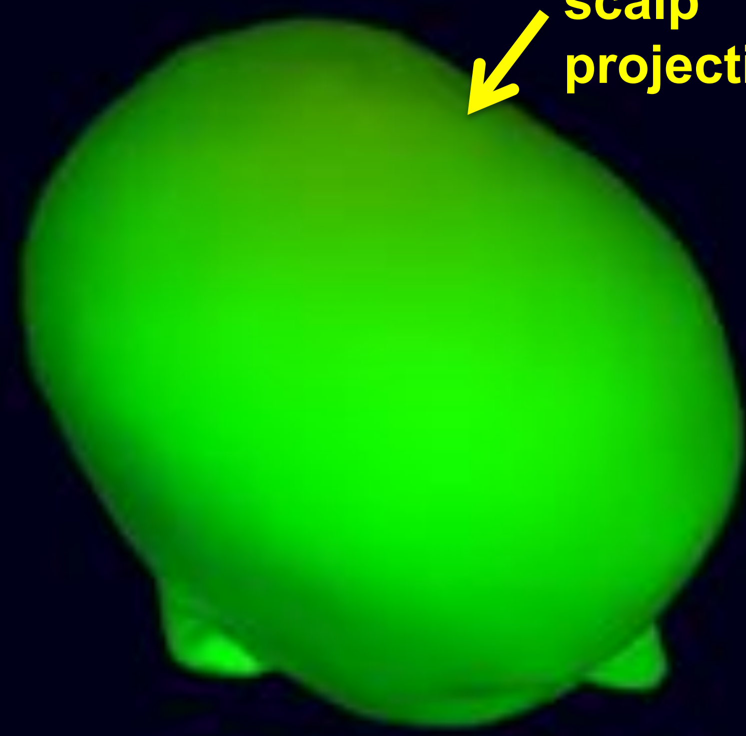
The *effective sources* of the scalp EEG & MEG are emergent islands of local synchrony / near-synchrony.



EEG Scalp Signal Illusion

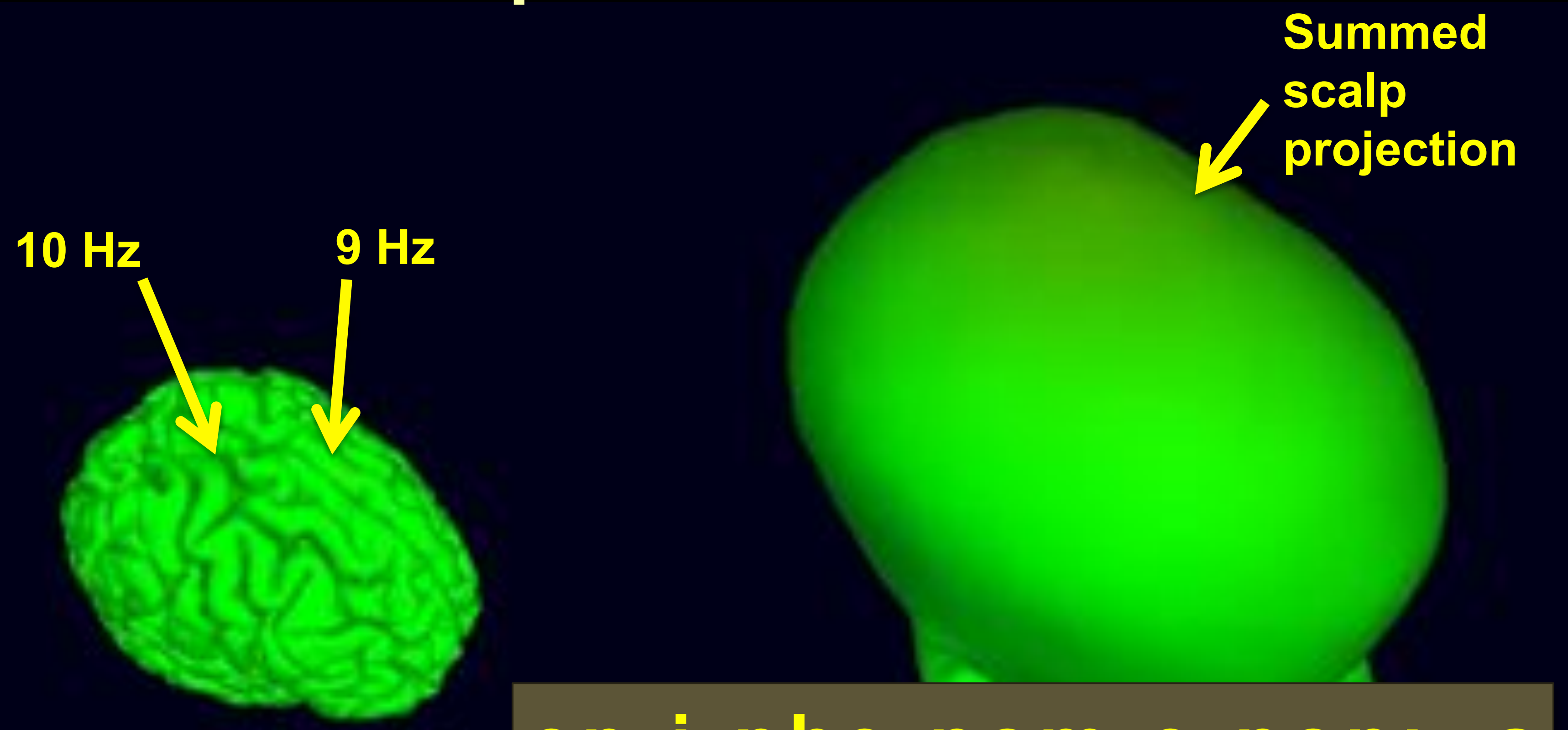


Two Effective Sources



Their summed scalp projection

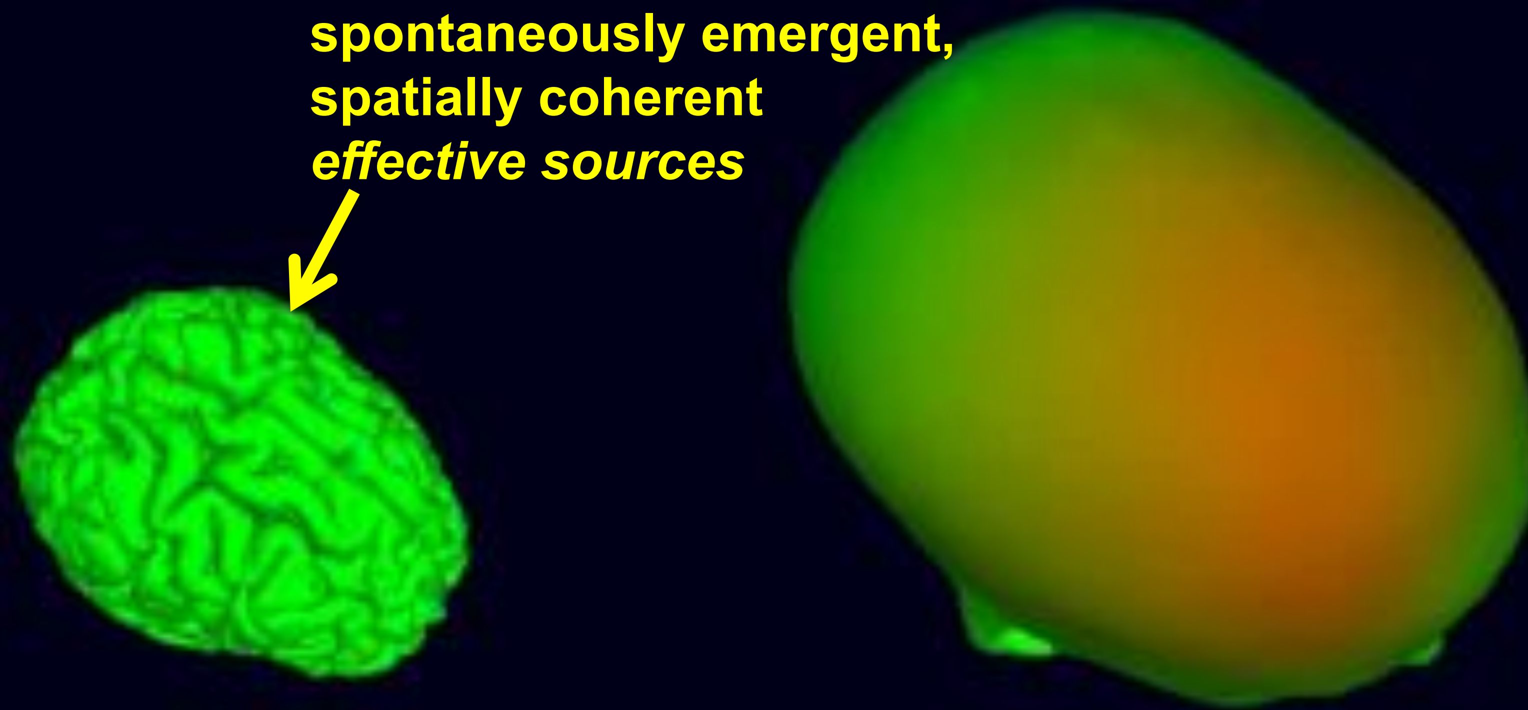
Scalp EEG Illusion



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

The very broad EEG point-spread function

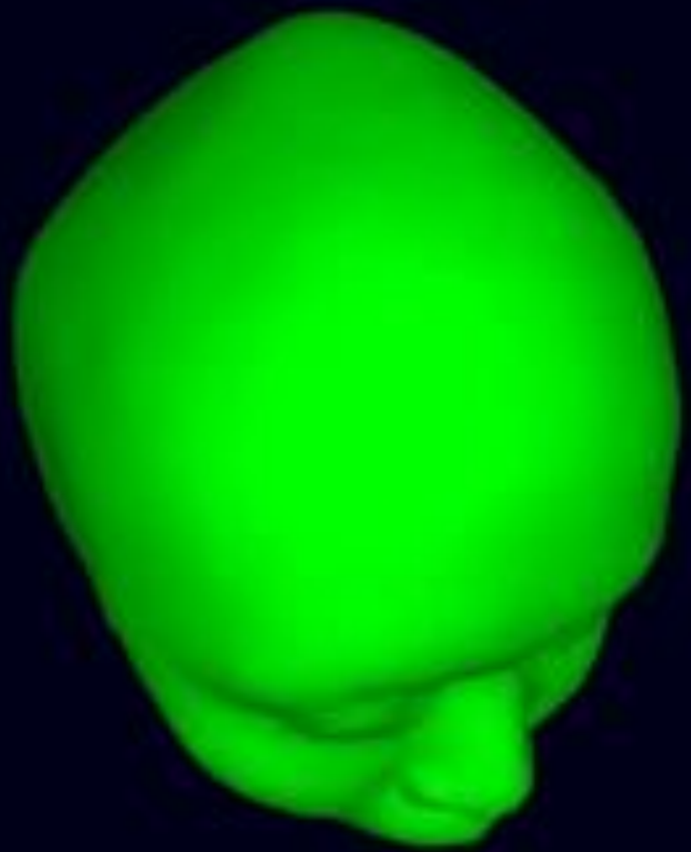
30
spontaneously emergent,
spatially coherent
effective sources



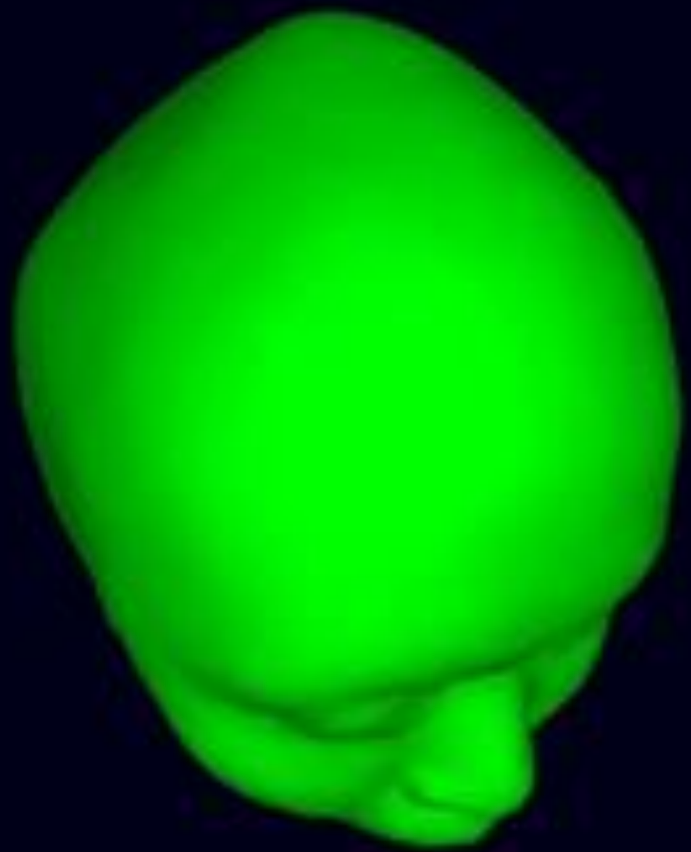
Simulated EEG summing 30 cortical effective sources (animation at 1/5th real time)

Akalin Acar & Makeig 2010

Non-brain ‘artifact’ contributions to scalp EEG



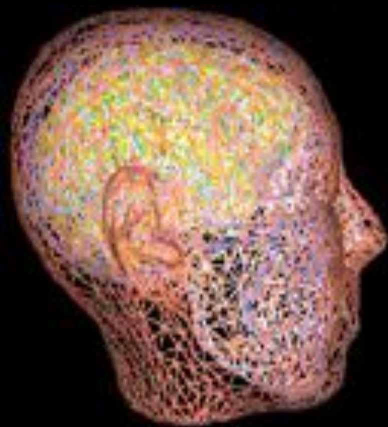
Brain sources only



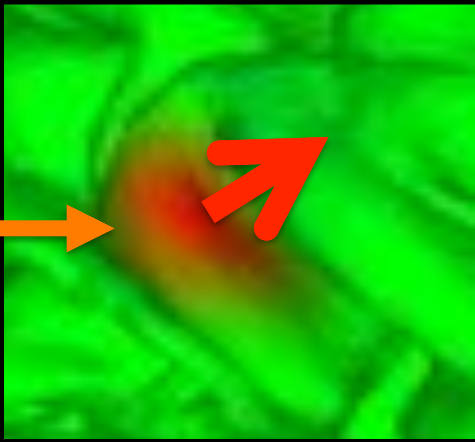
PLUS non-brain sources

Electromagnetic source localization using realistic head models

Solve the forward problem using realistic head models (BEM)



Simple Map



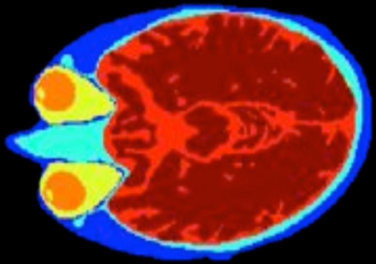
Source Estimate

Sensor Localization

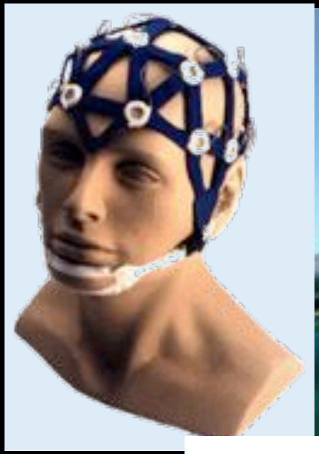
Signal Processing

Mesh generation

MRI



Segmentation



EEG/MEG

Zeynep Akalin Acar & Scott Makeig '06

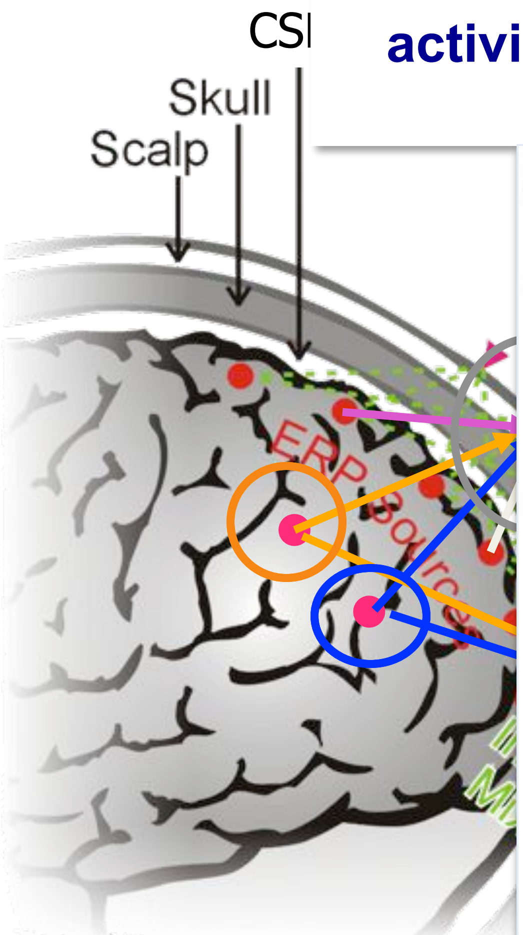
But how to find EEG simple maps ?

Makeig (2006)

Blind EEG Source Separation by Independent Component Analysis

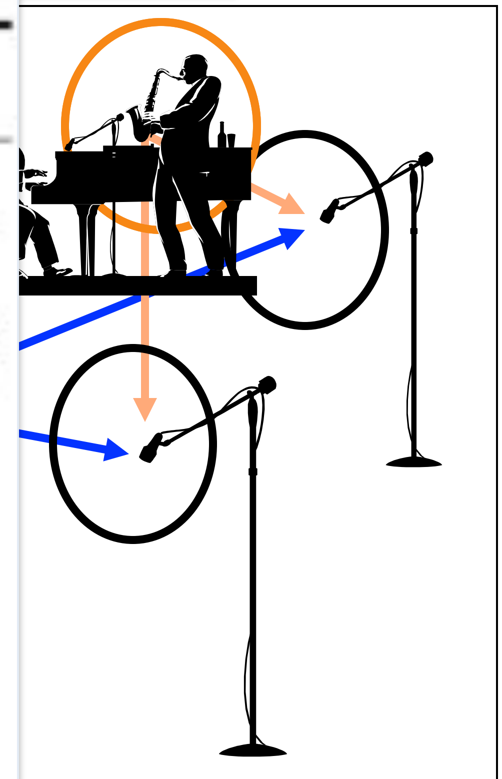
Tony Bell, developer of Infomax ICA

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



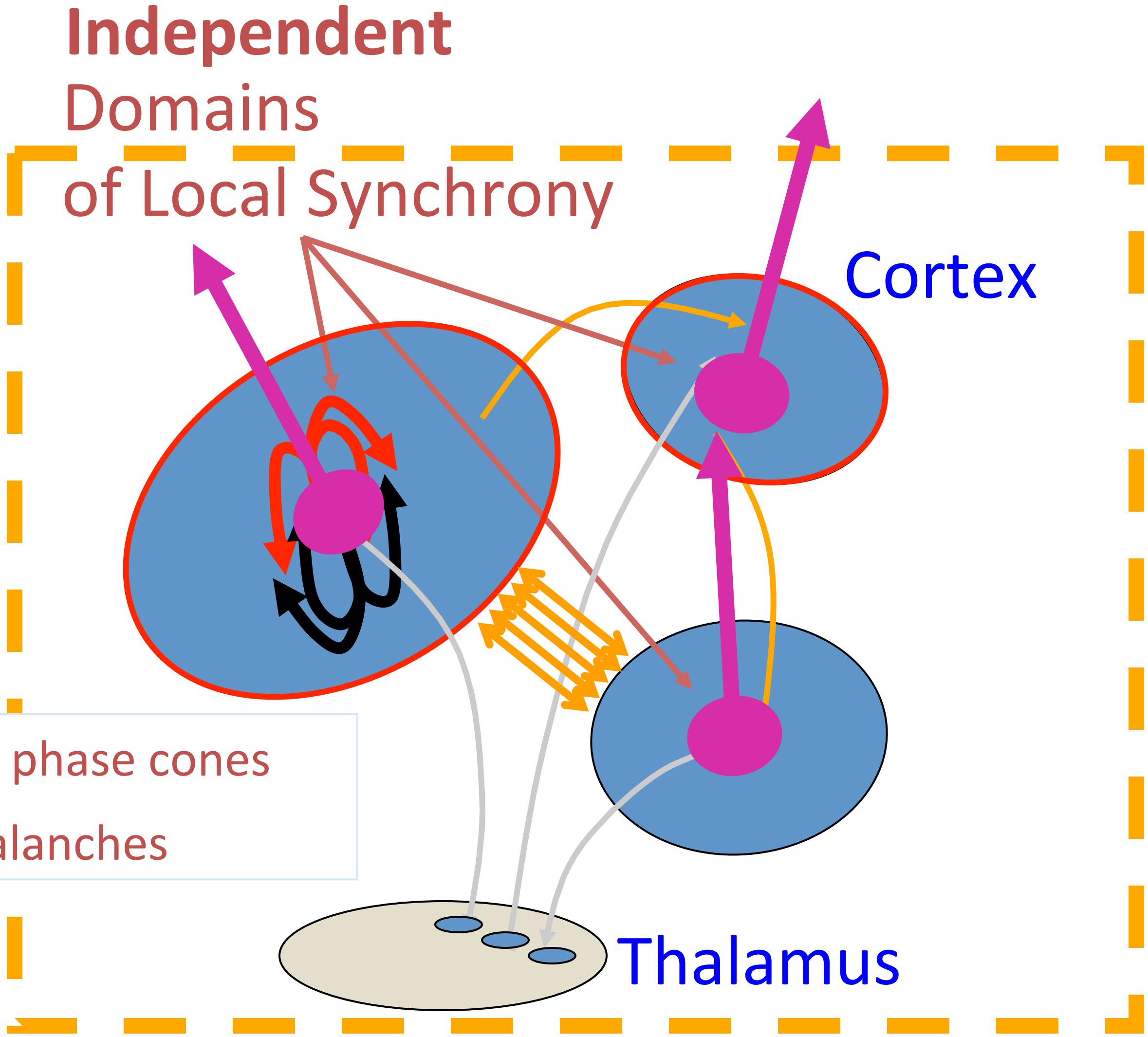
Independent Component Analysis of Electroencephalographic Data

Abstract



S. Makeig, S. Enghoff (2000)

Are EEG source signals ~independent?



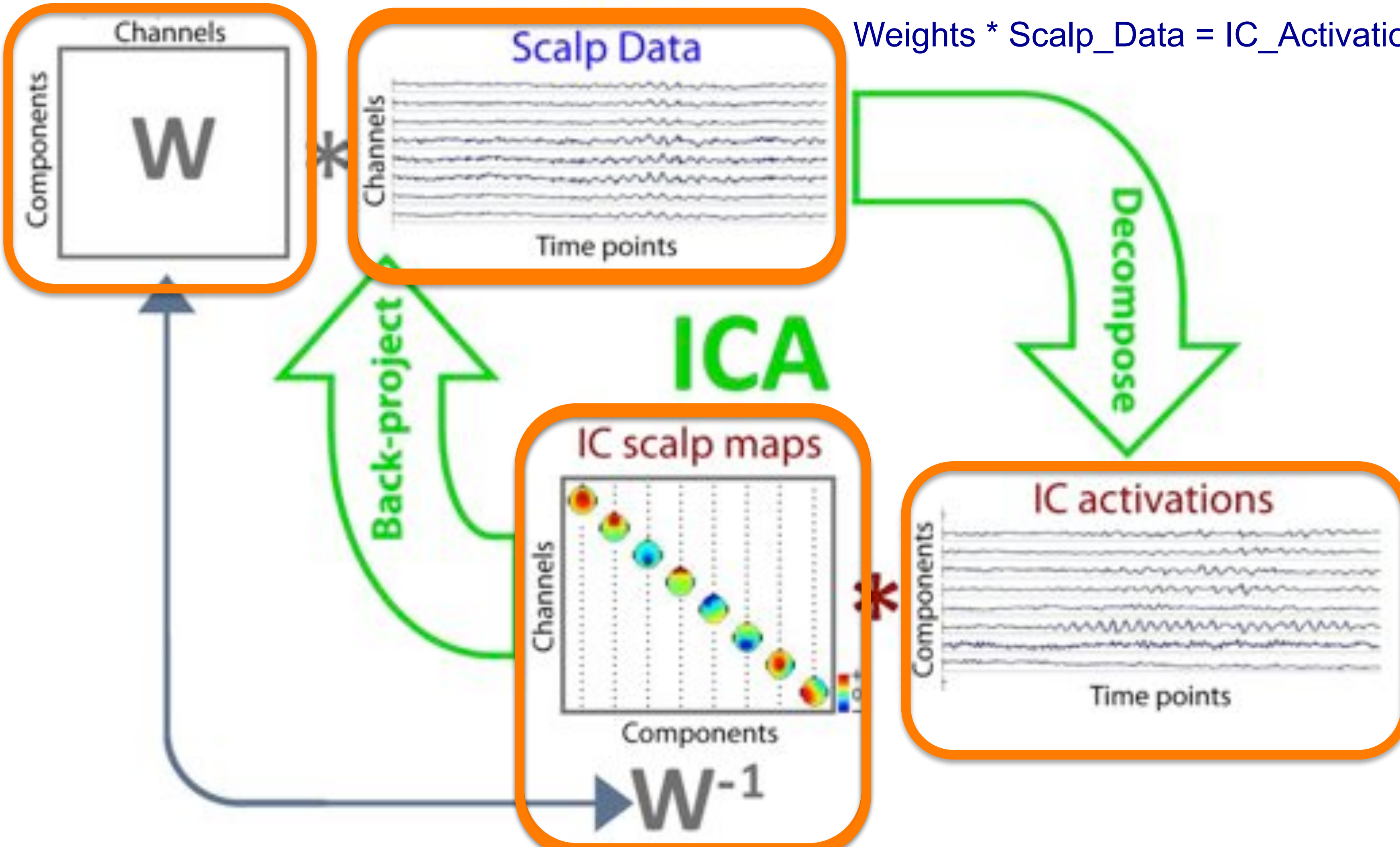
Freeman - phase cones

Plenz - avalanches

S. Makeig (2007)

ICA is a linear data decomposition method

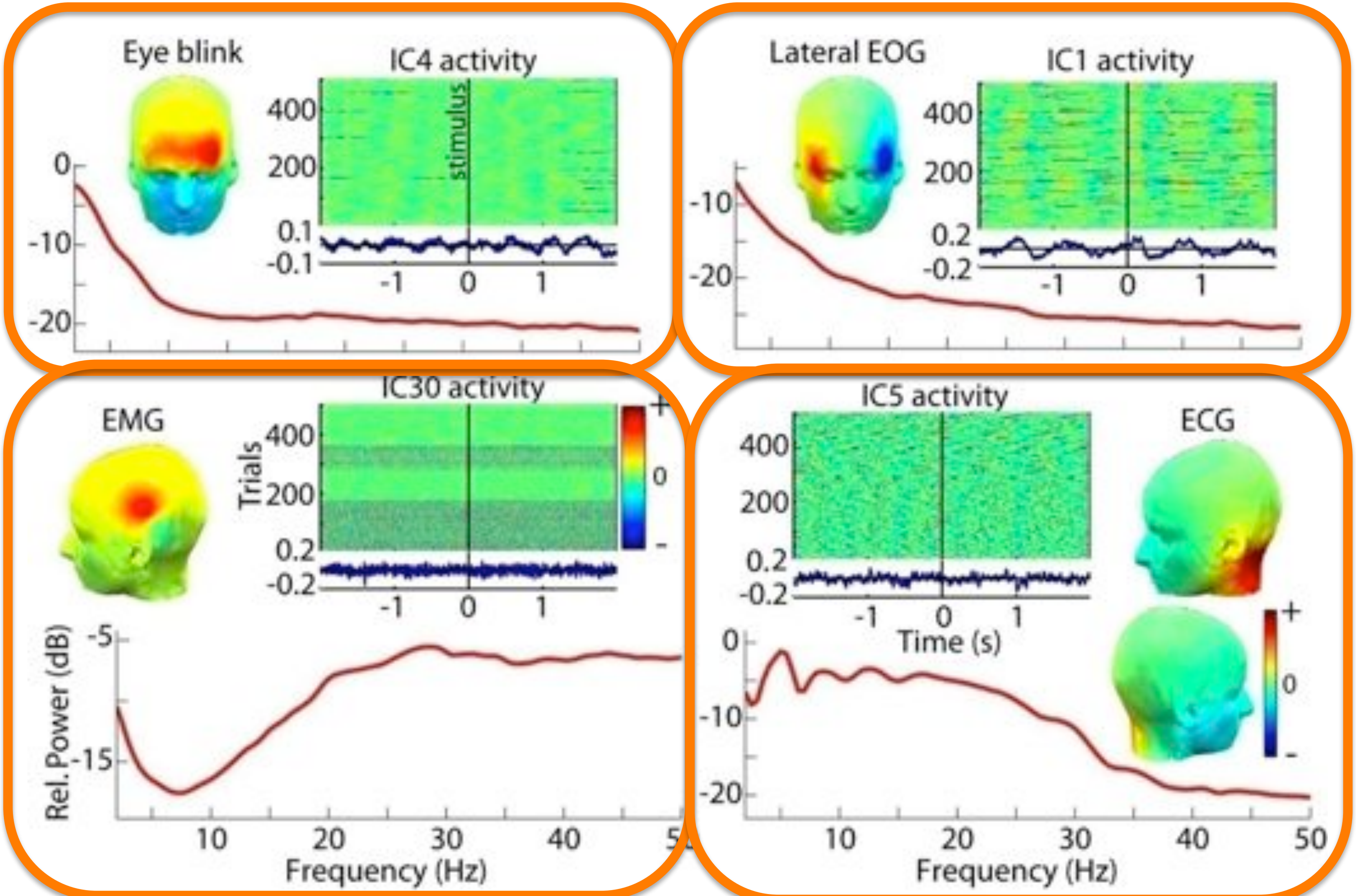
Weights * Scalp_Data = IC_Activations



Weights^{-1} * IC_Activations = Scalp_Data

Makeig & Onton, 2011

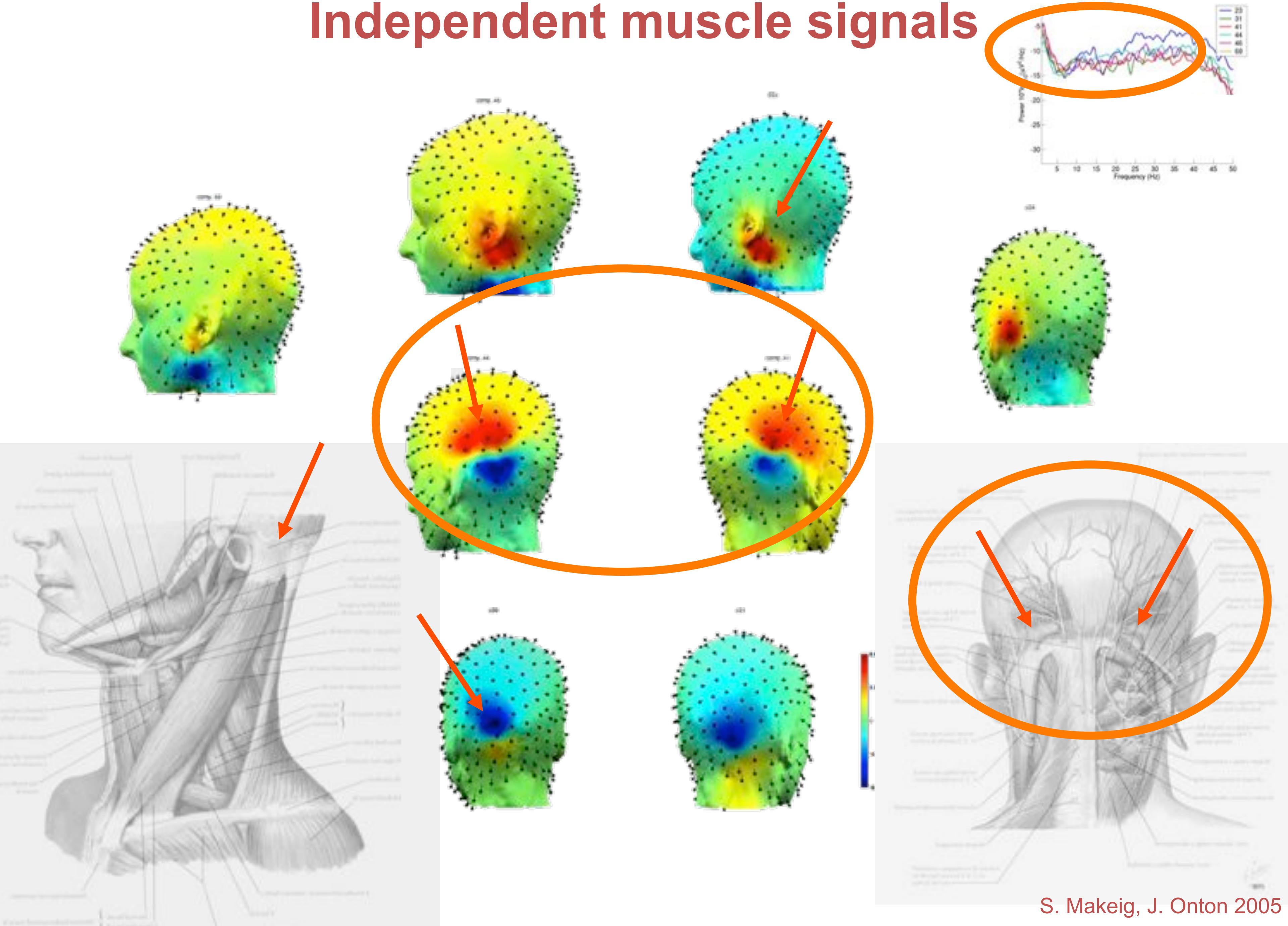
ICA finds Non-Brain Independent Component (IC) Processes …



… separates them from the remainder of the data …

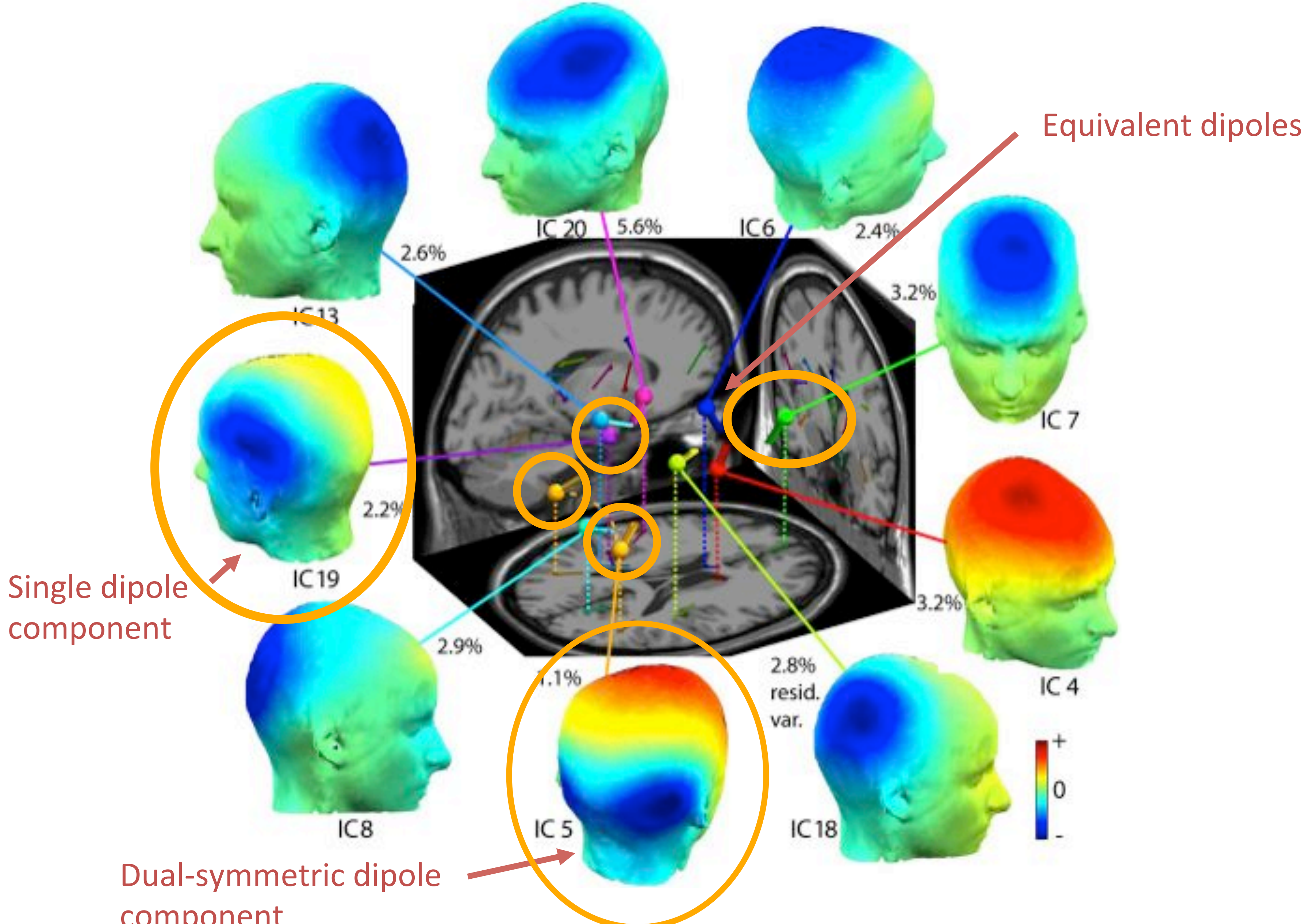
J. Onton & S. Makeig 2006

Independent muscle signals



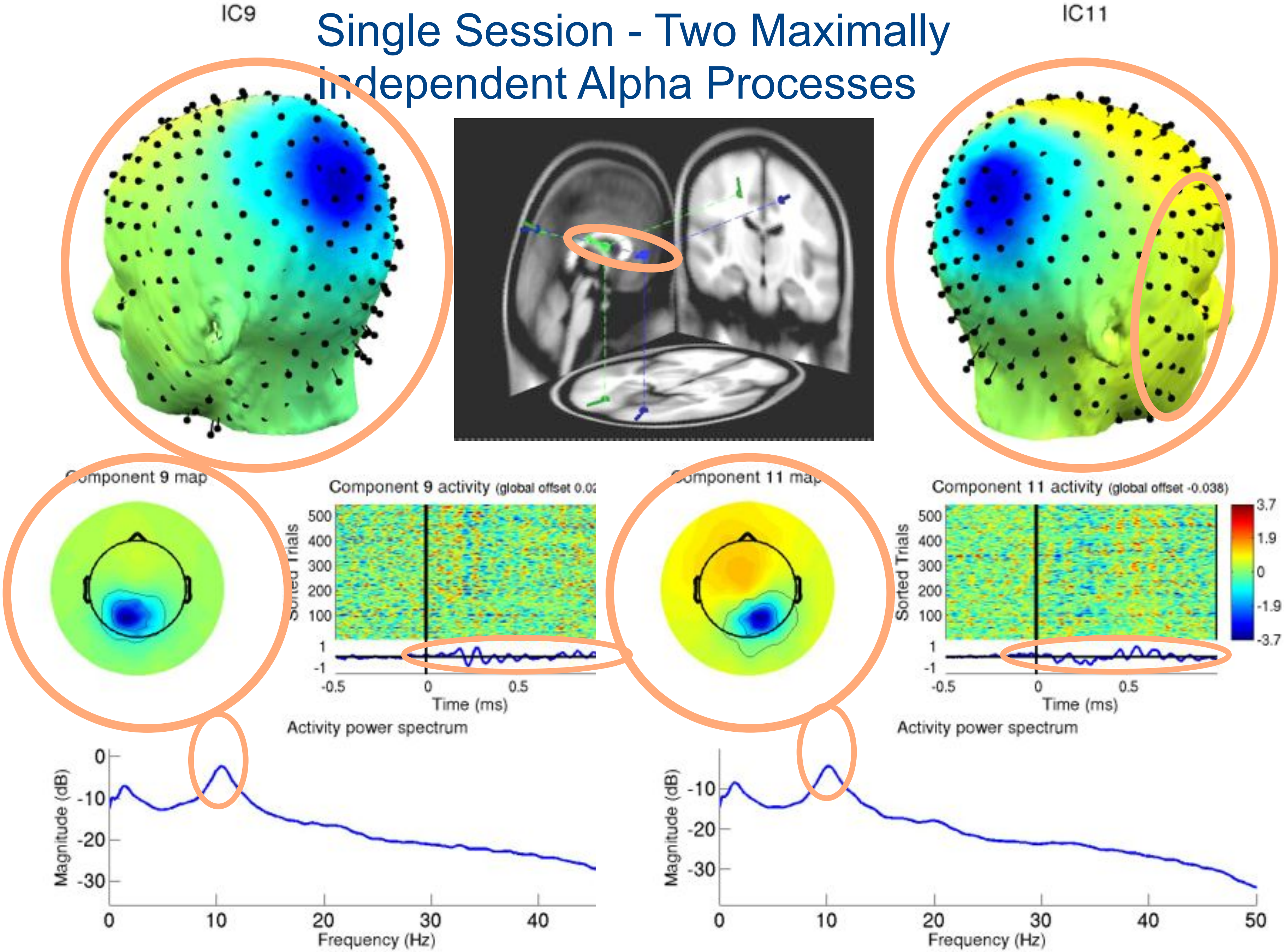
S. Makeig, J. Onton 2005

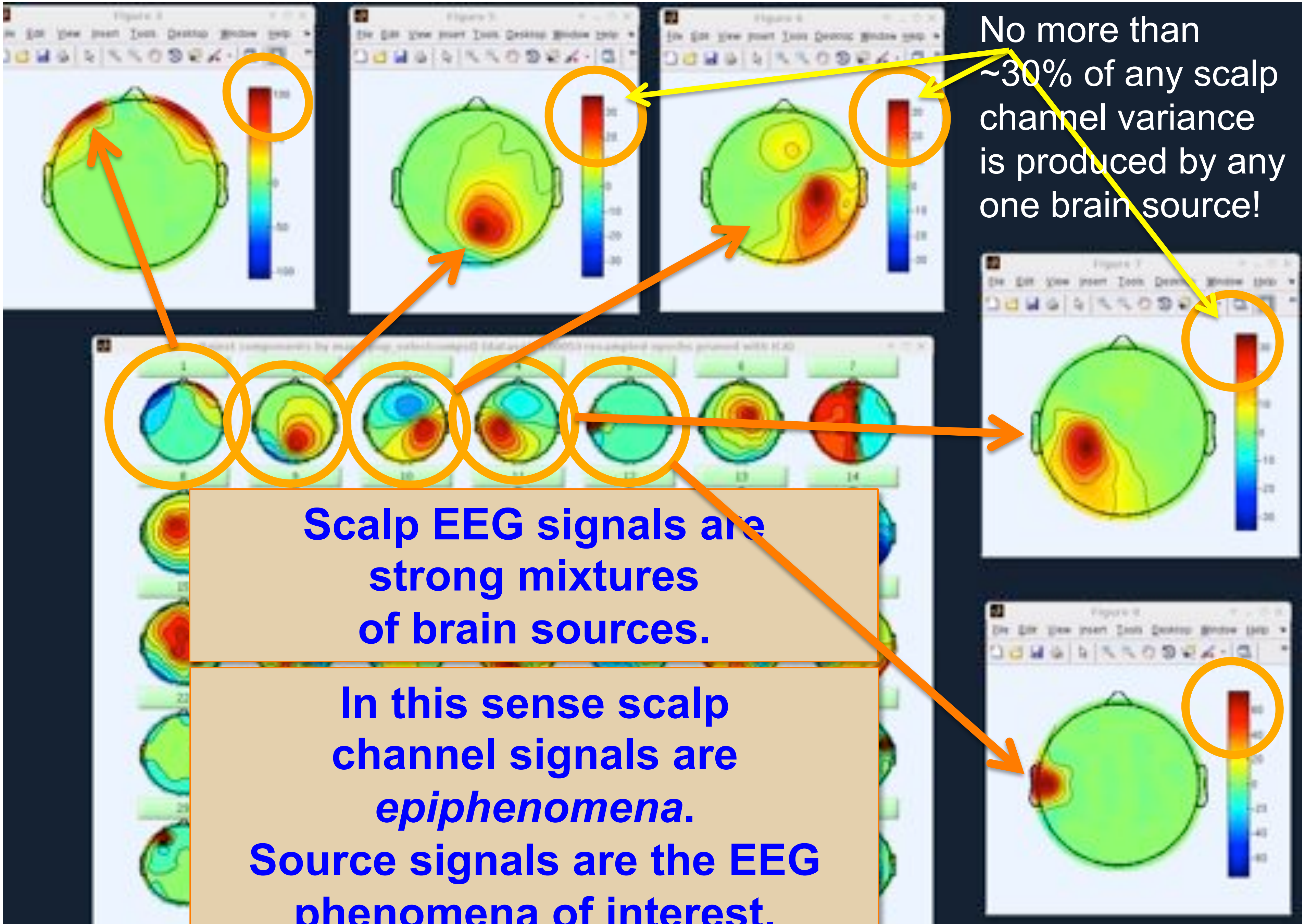
… and also separates cortical brain IC processes



Julie Onton & S. Makeig (2006)

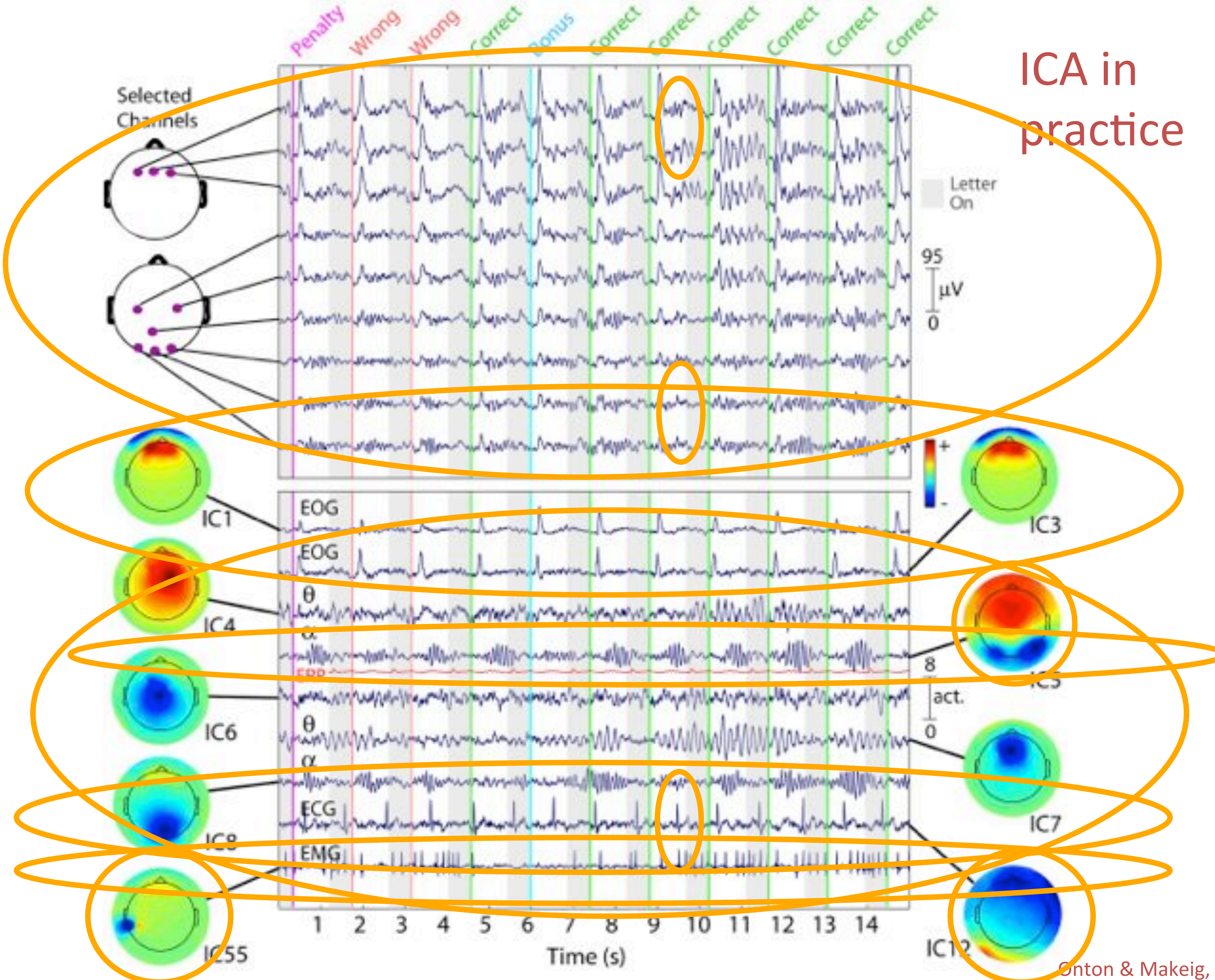
Single Session - Two Maximally Independent Alpha Processes



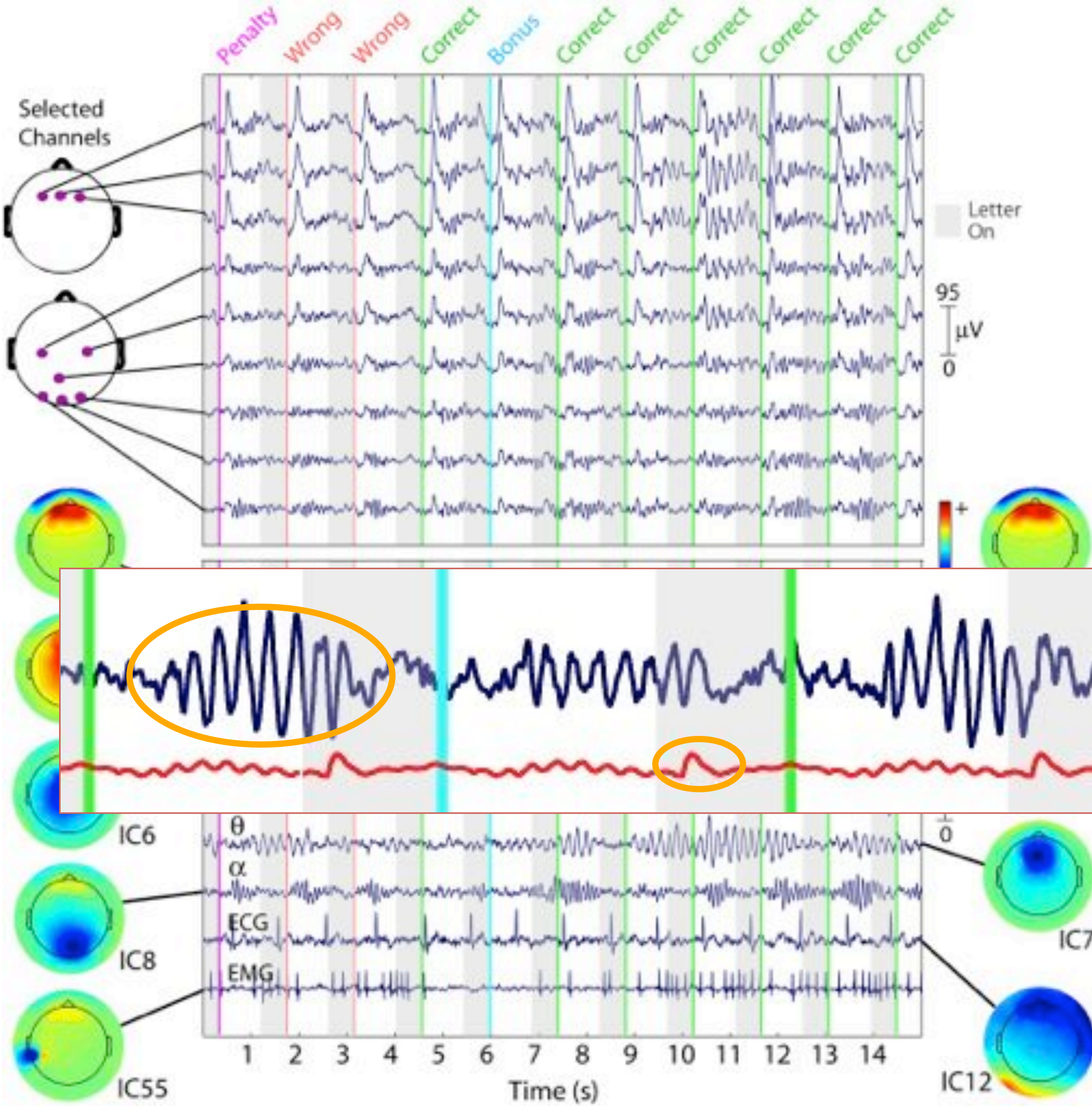


S. Makeig & M. Miyakoshi, 2015

ICA in practice



Onton & Makeig, 2006



Onton, Makeig (2006)

Important Recent Result

Those linear decompositions of multi-channel EEG data that find ICs whose time courses are **more** temporally **independent**

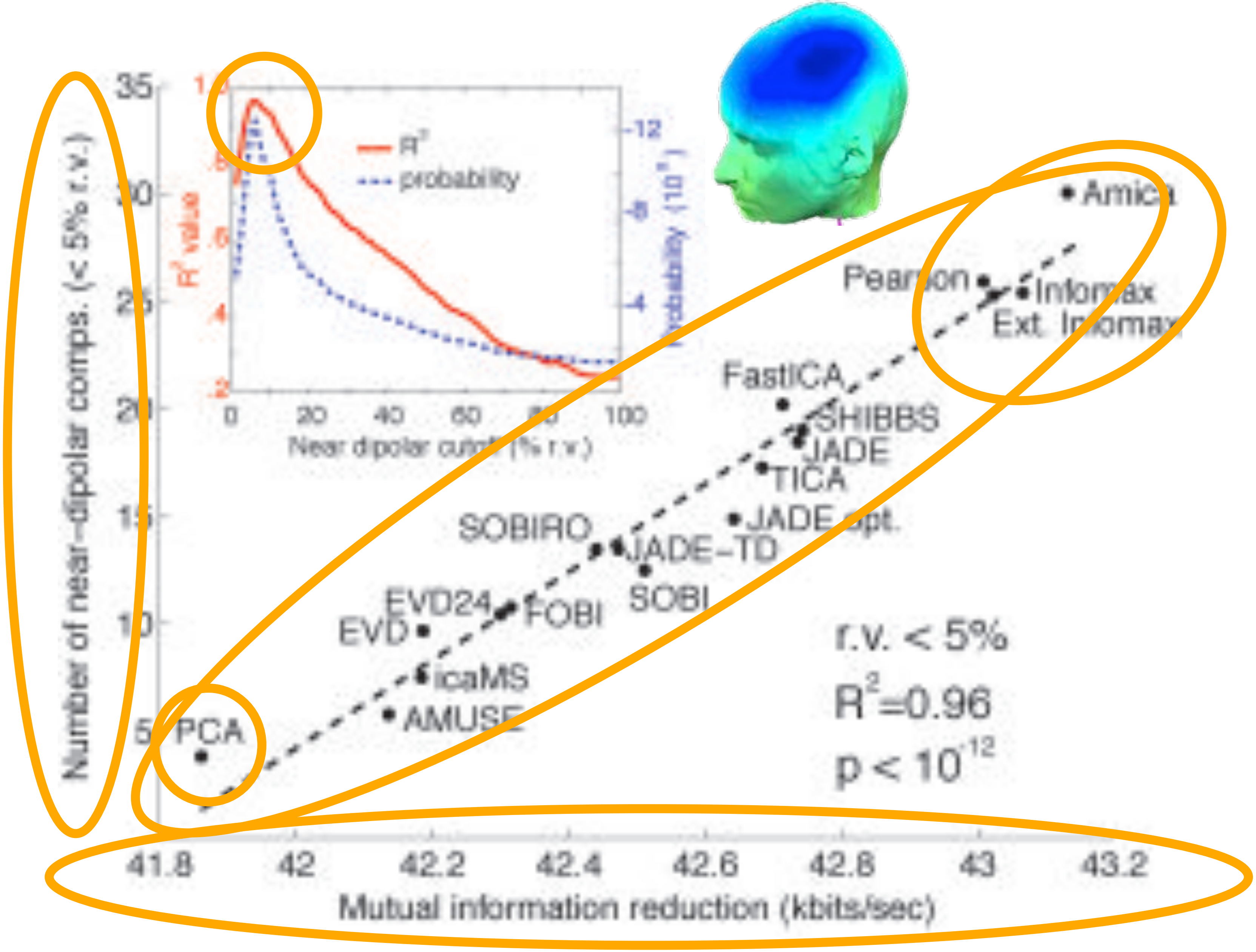
Also find more ICs whose scalp maps are highly '**dipolar**' – i.e., ICs compatible with the spatial projection of a single local cortical (or non-brain, artifactual) source process – whose location can be identified.

More independent time courses ←→ Larger number of dipolar ICs

Dipolar ICs = Localized cortical source processes

Delorme et al., *PLOS One*, 2012

S. Makeig, 2011

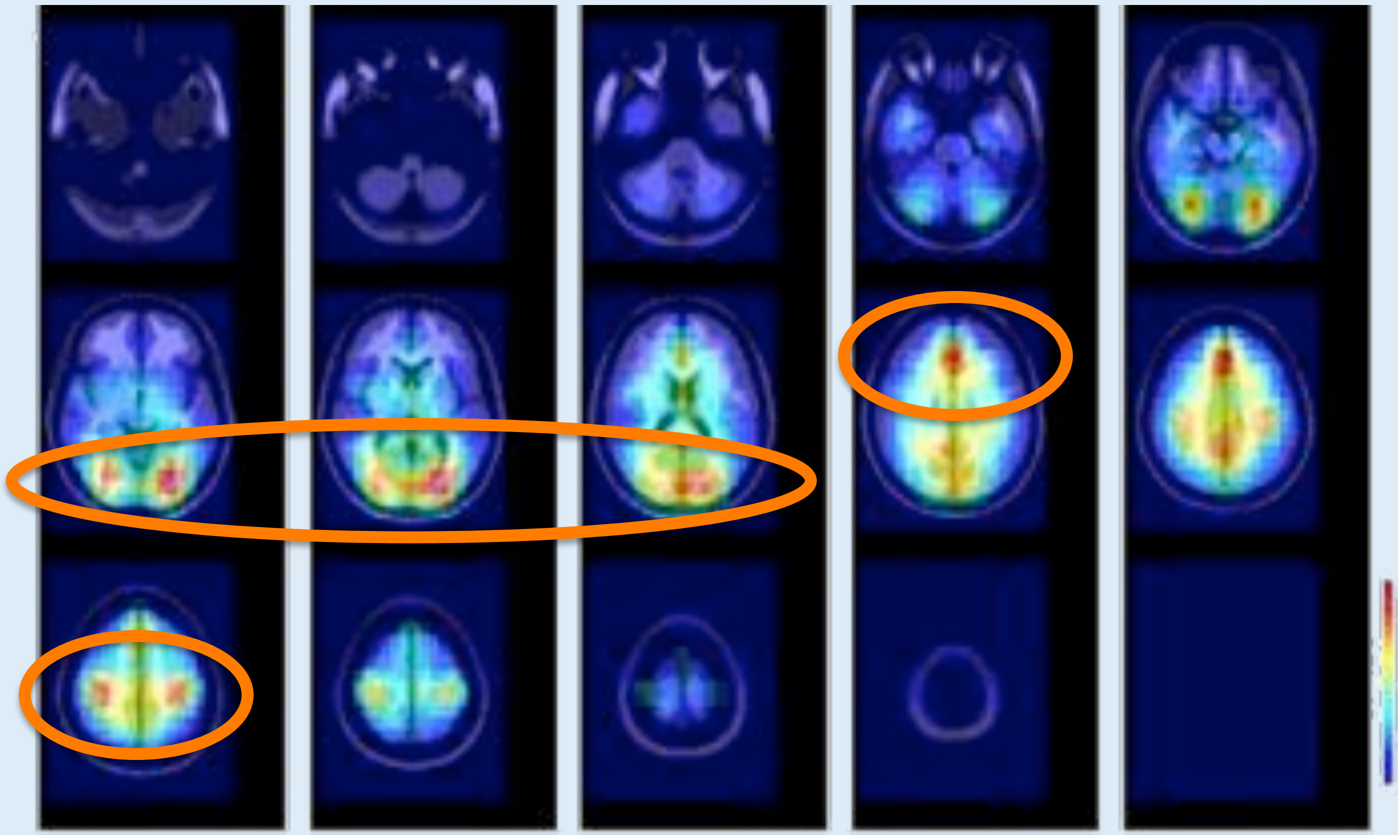


Delorme et al., *PLOS One*, 2012

S. Makeig, 2011

Equivalent dipole density

Visual Working Memory

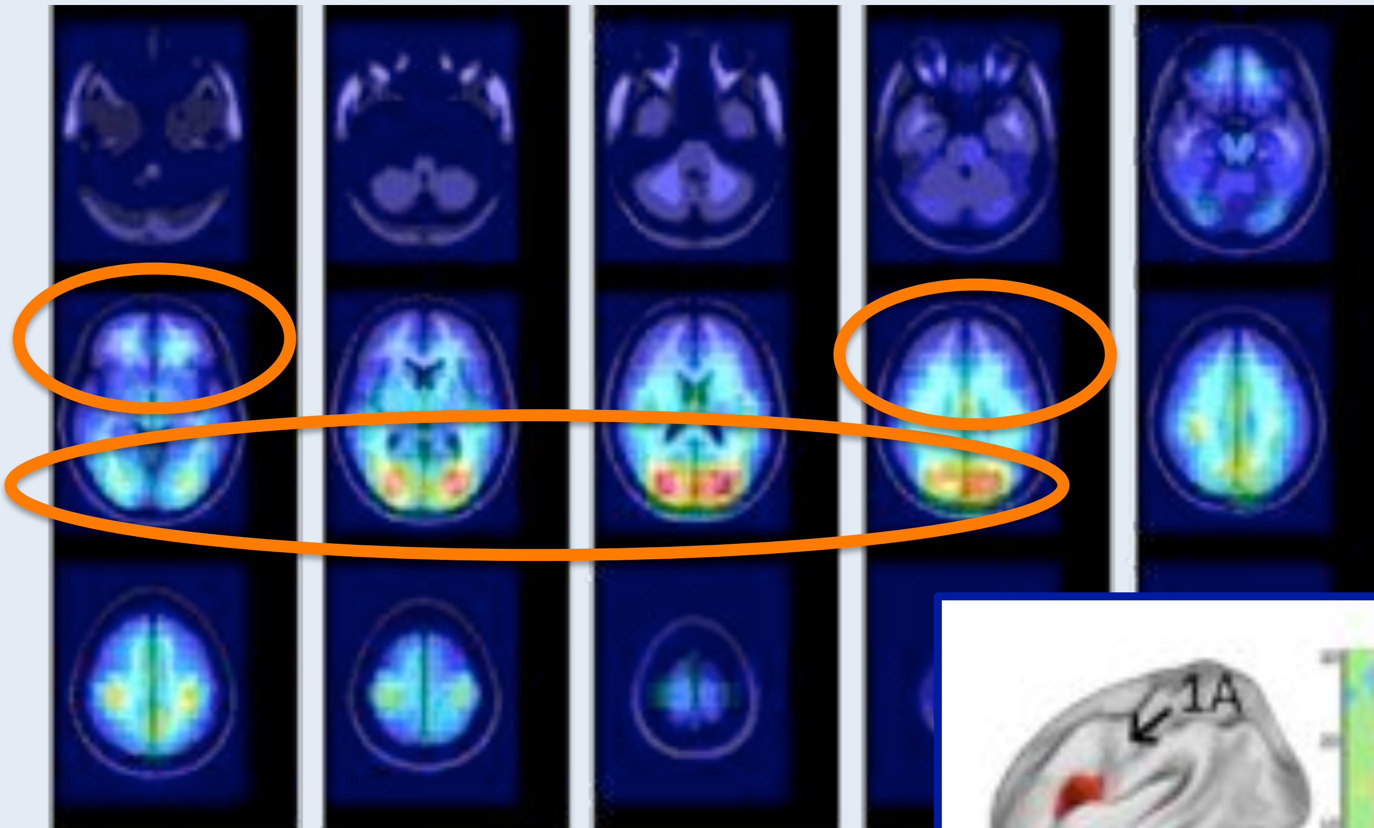


Sternberg letter memory task

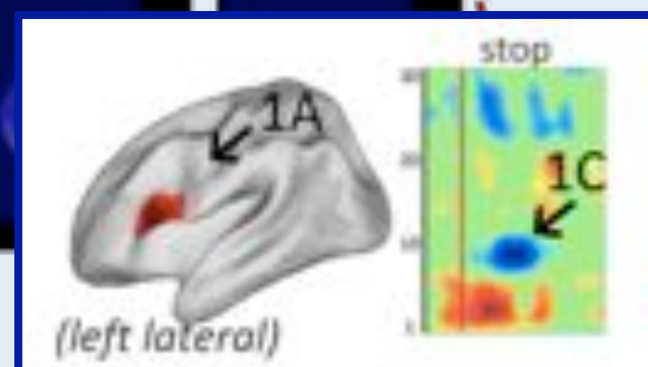
Onton et al., 2005

Onton et al., '05

Equivalent dipole density



Eyes closed emotion imagination



>> dipoledensity()

Onton et al., '05

Questions … ?