

Mining Cognitive Brain Dynamics I



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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.

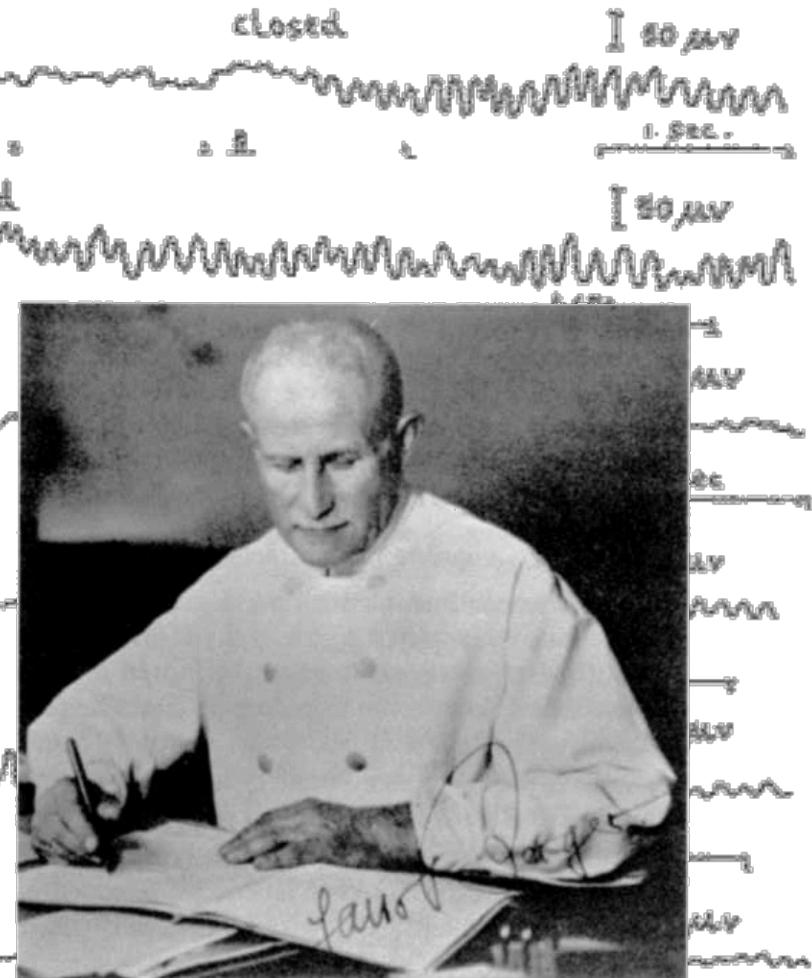
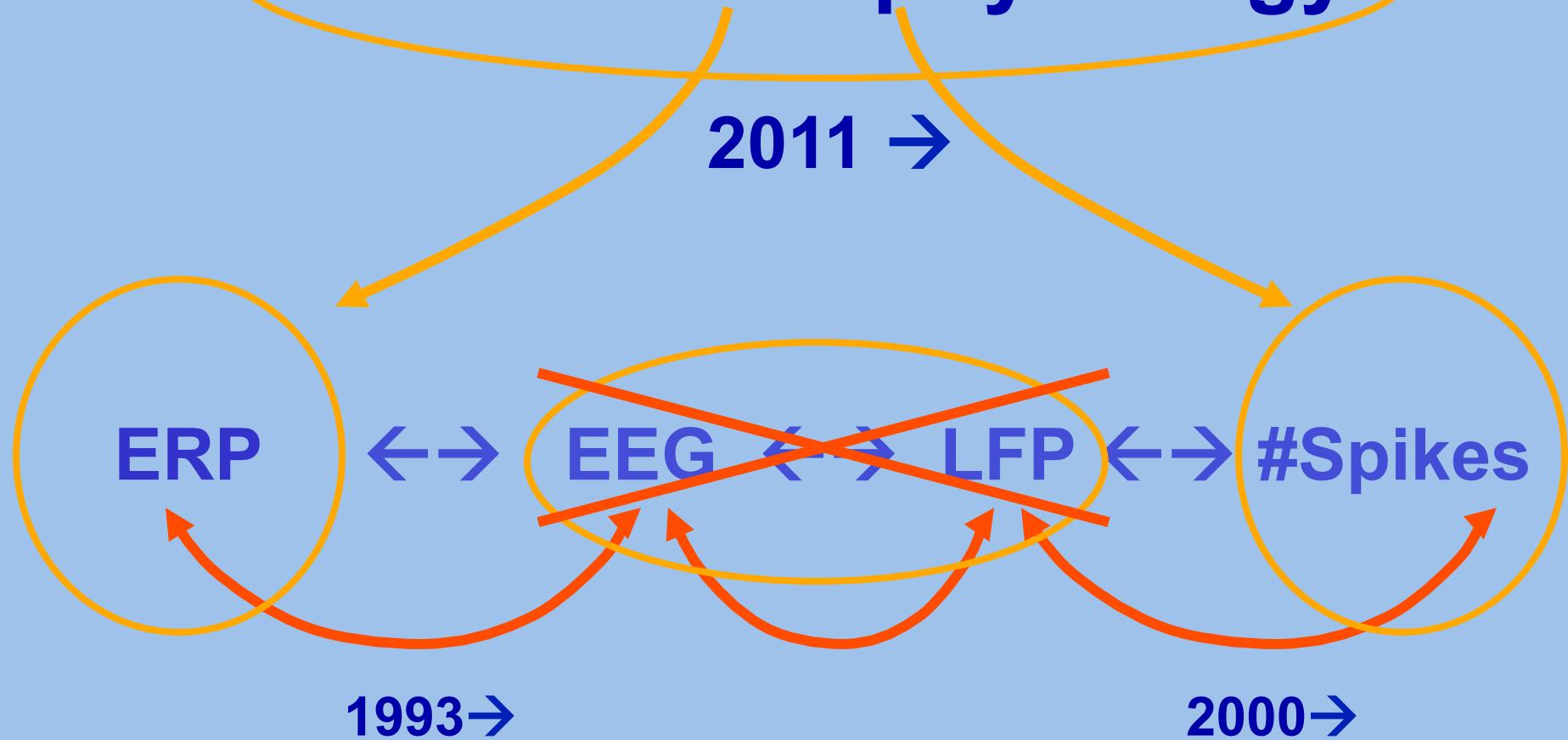
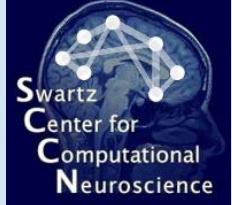


FIGURE 1-1.—Professor Hans Berger (1873–1941), neuro-psychiatrist, University of Jena, Jena, Germany, first to discover and describe in 1929 a unique kind of electrical activity recorded from the brain of man, which he named the electroencephalogram (Elektrenkephalogramm).

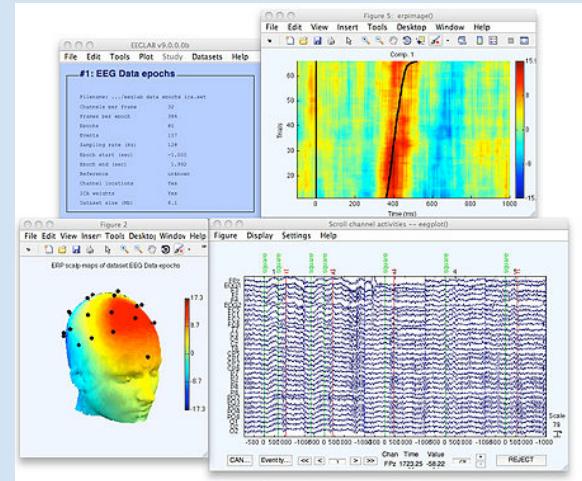
Brain Electrophysiology





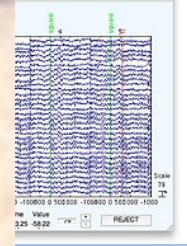
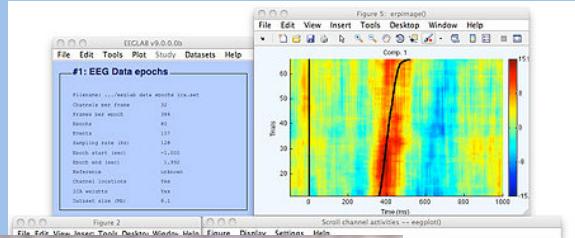
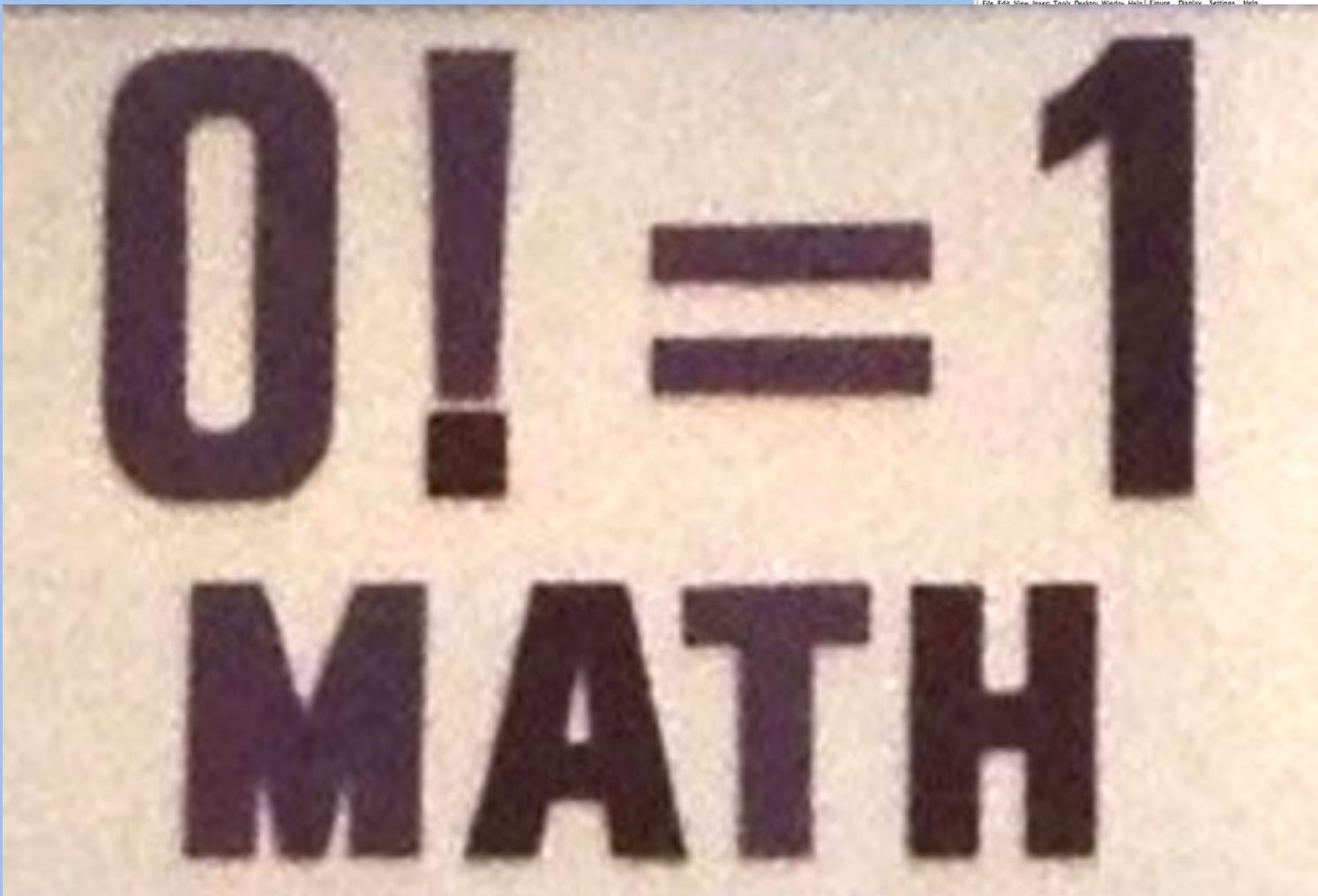
EEGLAB History

- 1993 – ERSP / ITC (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 – 1st EEGLAB (sccn.ucsd.edu)
- 2004 - 1st EEGLAB plug-ins
- 2006 - 1st EEGLAB STUDY structure and component clustering tools
- 2009 – NFT (Neuroelectromagnetic Forward Head Modeling Toolbox)
- 2009 – New toolboxes: SIFT, BCILAB, MPT
- 2012 - HeadIT resource, ERICA (Experimental Real-time Interactive Control & Analysis)
- 2012 – Workshop in Beijing; LSL framework; XDF data format; SNAP exp control
- 2013 – NIH project funding renewed; workshops in Aspet and San Diego; HeadIT.org online

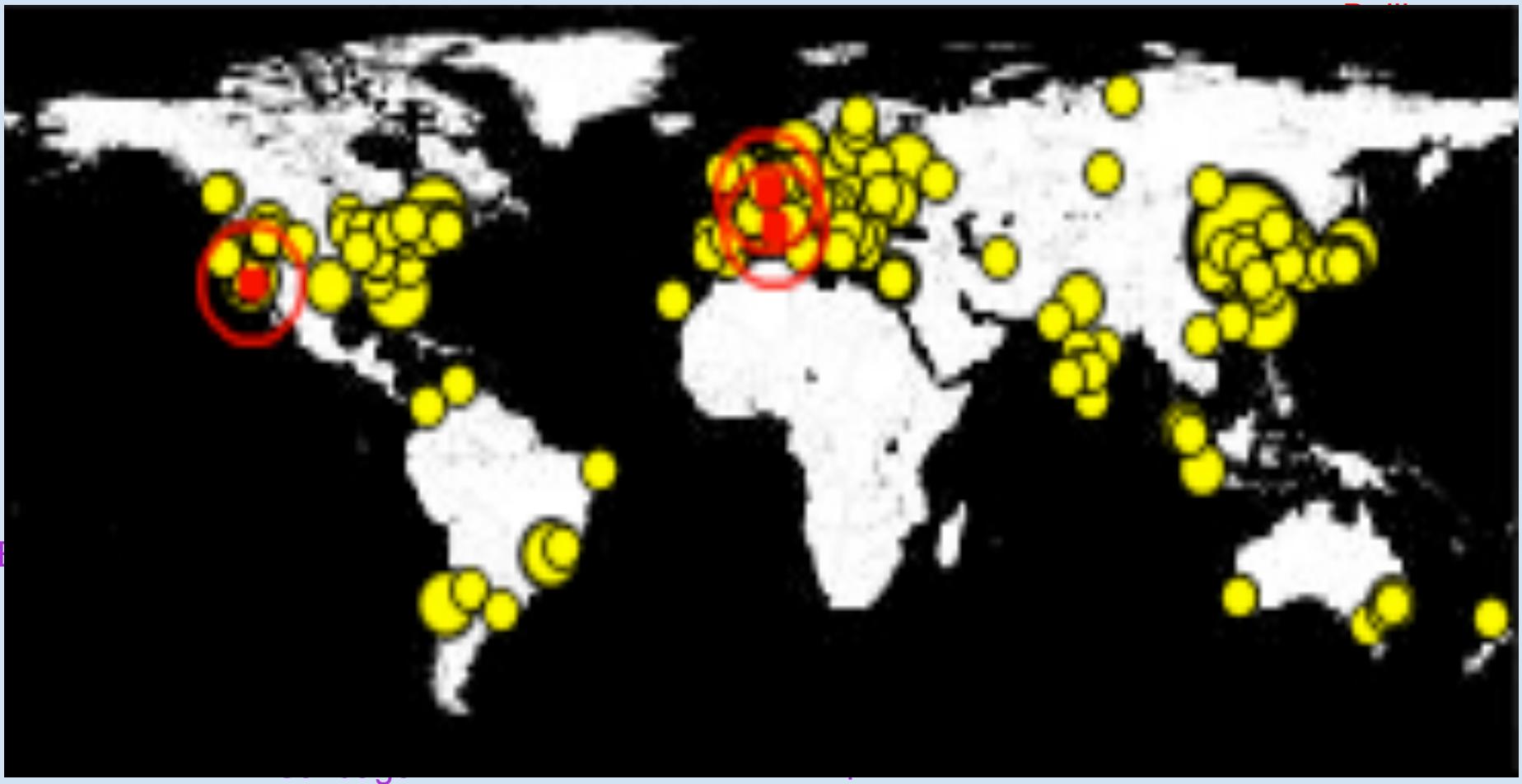




Toulouse Math



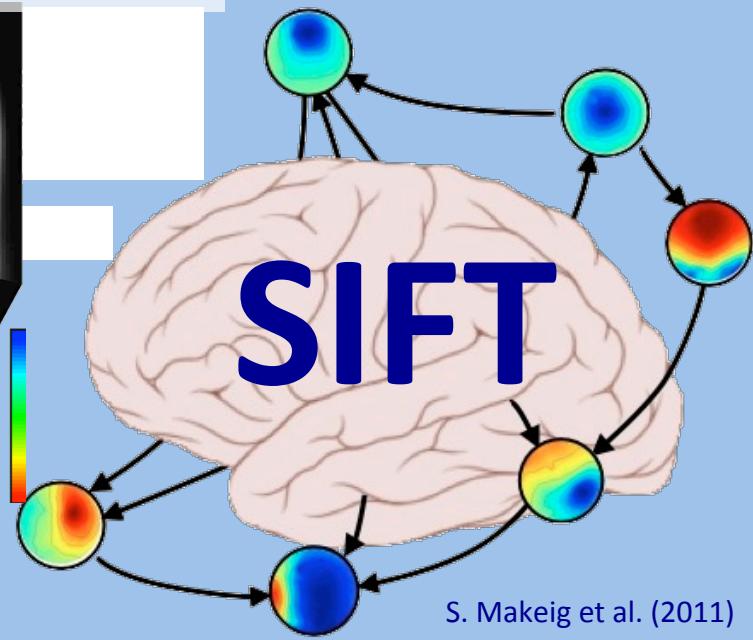
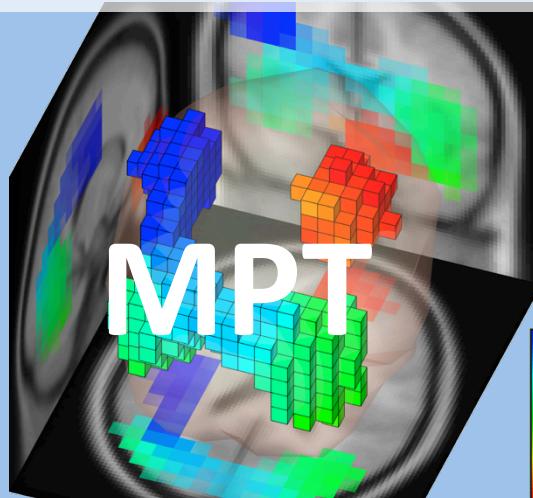
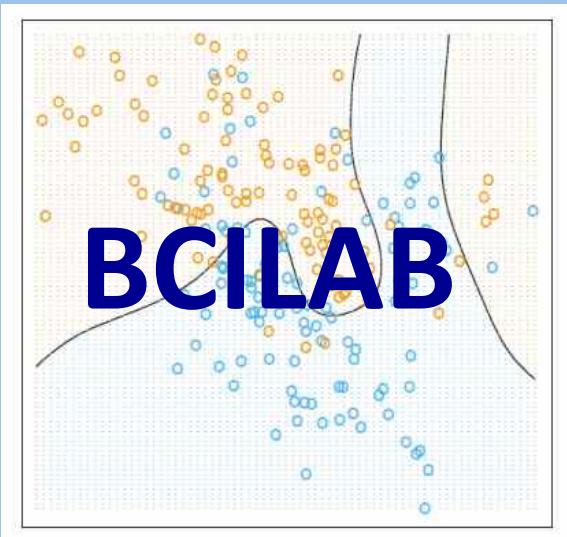
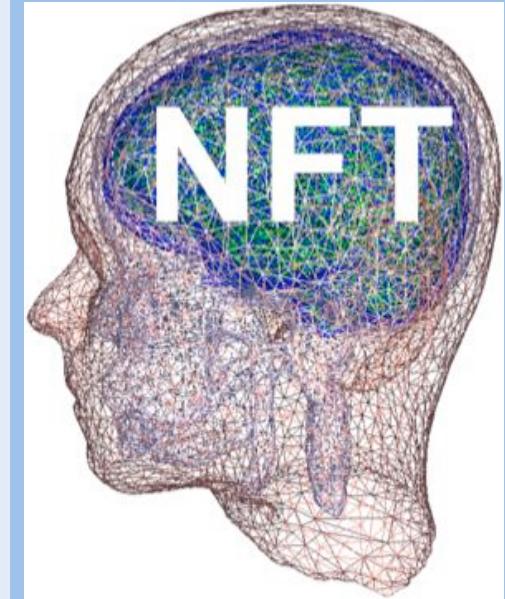
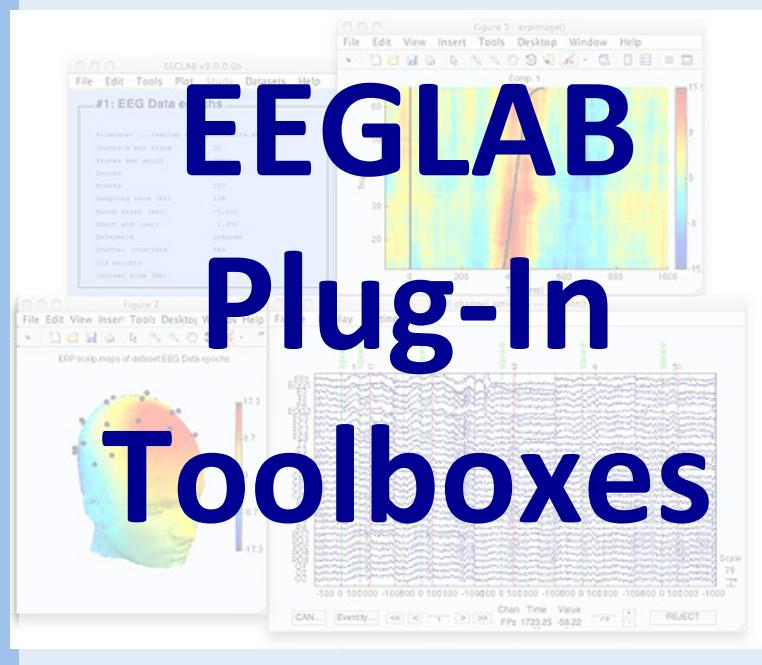
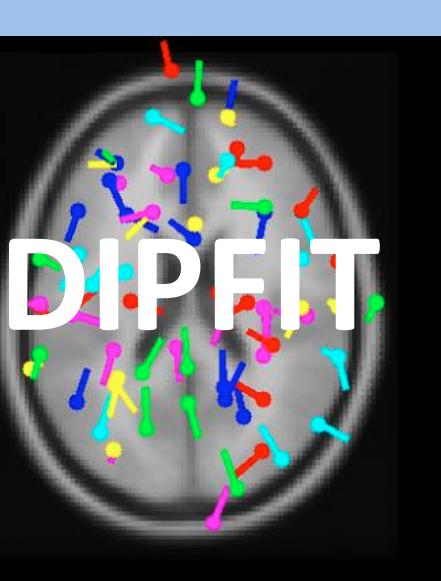
EEGLAB Workshops



Swartz Center for Computational Neuroscience, UCSD



10th Anniversary SCCN Impromptu celebration 1/2/12



S. Makeig et al. (2011)

I gaped ...
I tossed ...
I jutted ...
I ducked
I answered ...

Who

I reached
I threw
I ran ...
pointed ...
I shot ...
I am I?
I saw ...

am I?

I realized that ...

It struck me that ...

I wondered ...

All of a sudden ...

Distributed Brain Dynamic Events

I noticed that ...

I decided that ...

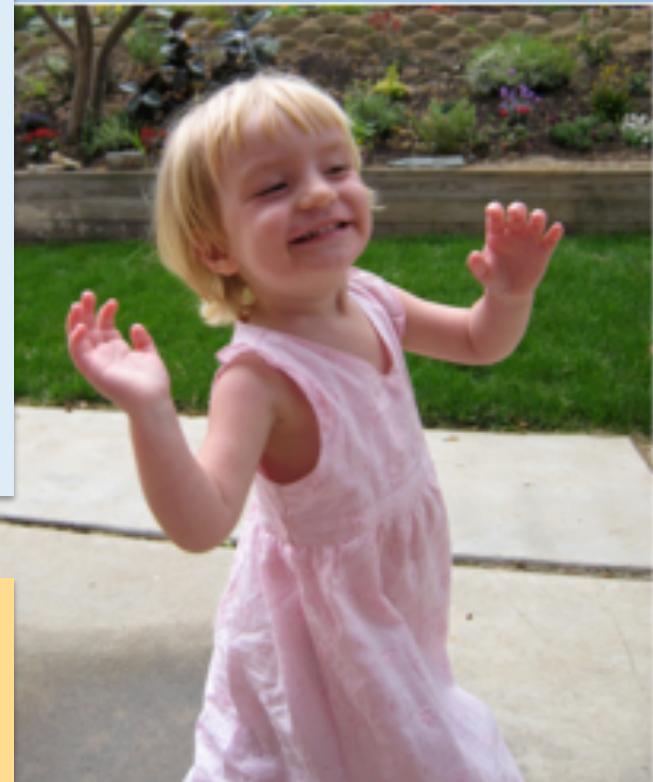
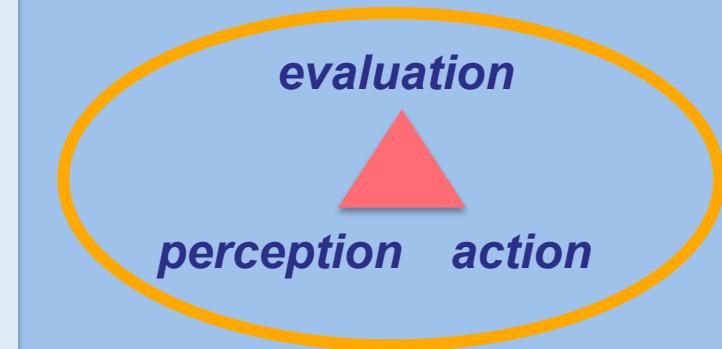
It occurred to me that ...

I imagined ...

I searched the scene for ...

Embodied 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?

Brain dynamics are inherently multi-scale

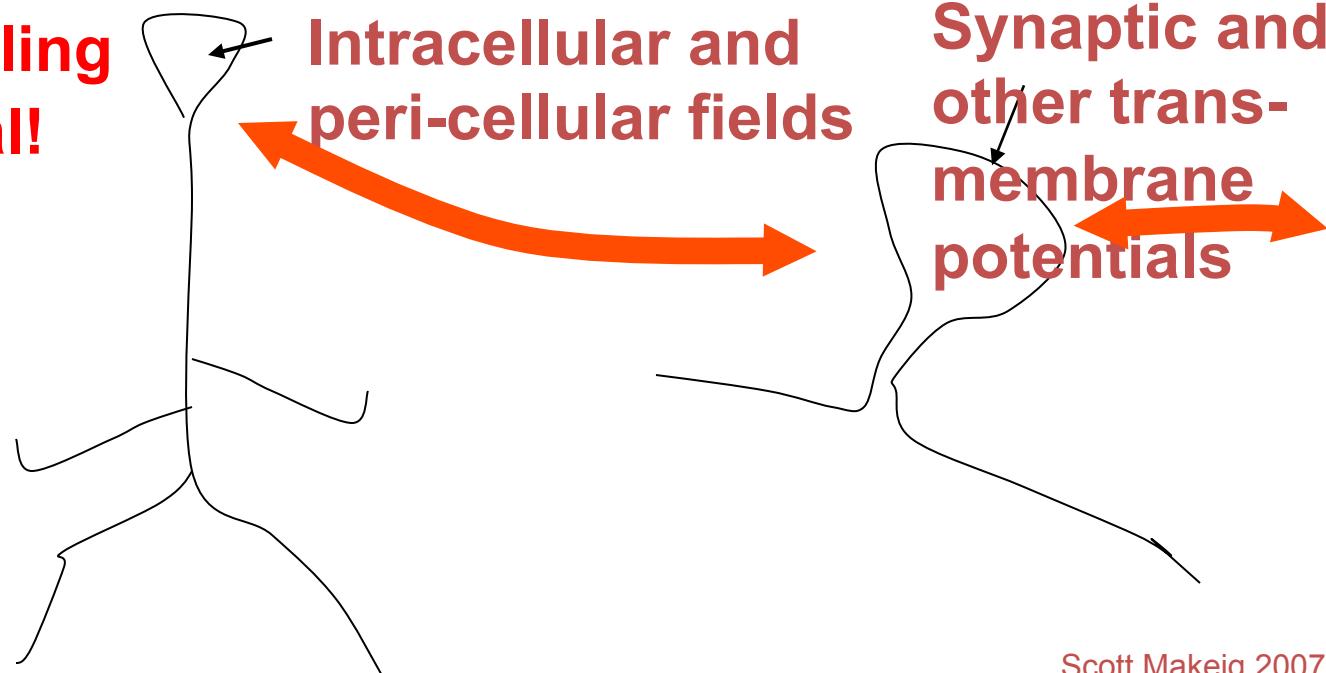
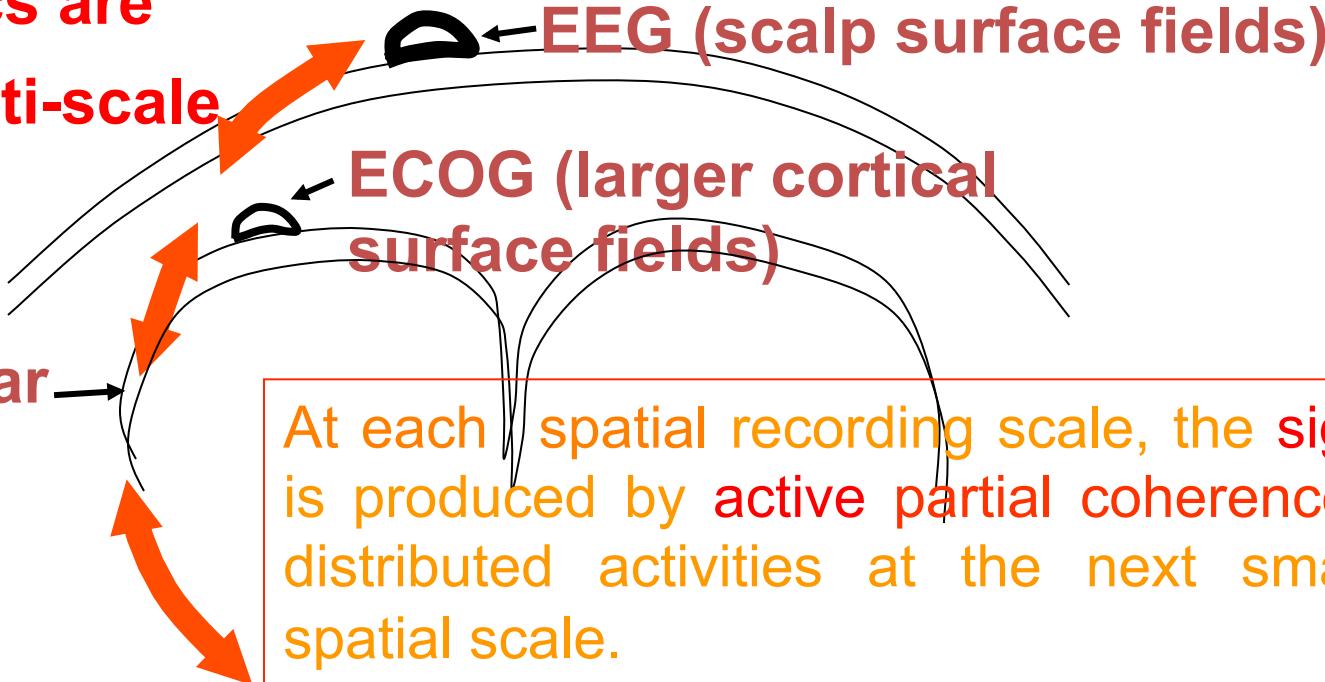
Local
Extracellular
Fields

Cross-scale coupling is bi-directional!

Larger



Smaller



Brain dynamics are inherently multi-scale

Local
Extracellular
Fields

SCALE CHAUVINISM

Cross-scale coupling is bi-directional!

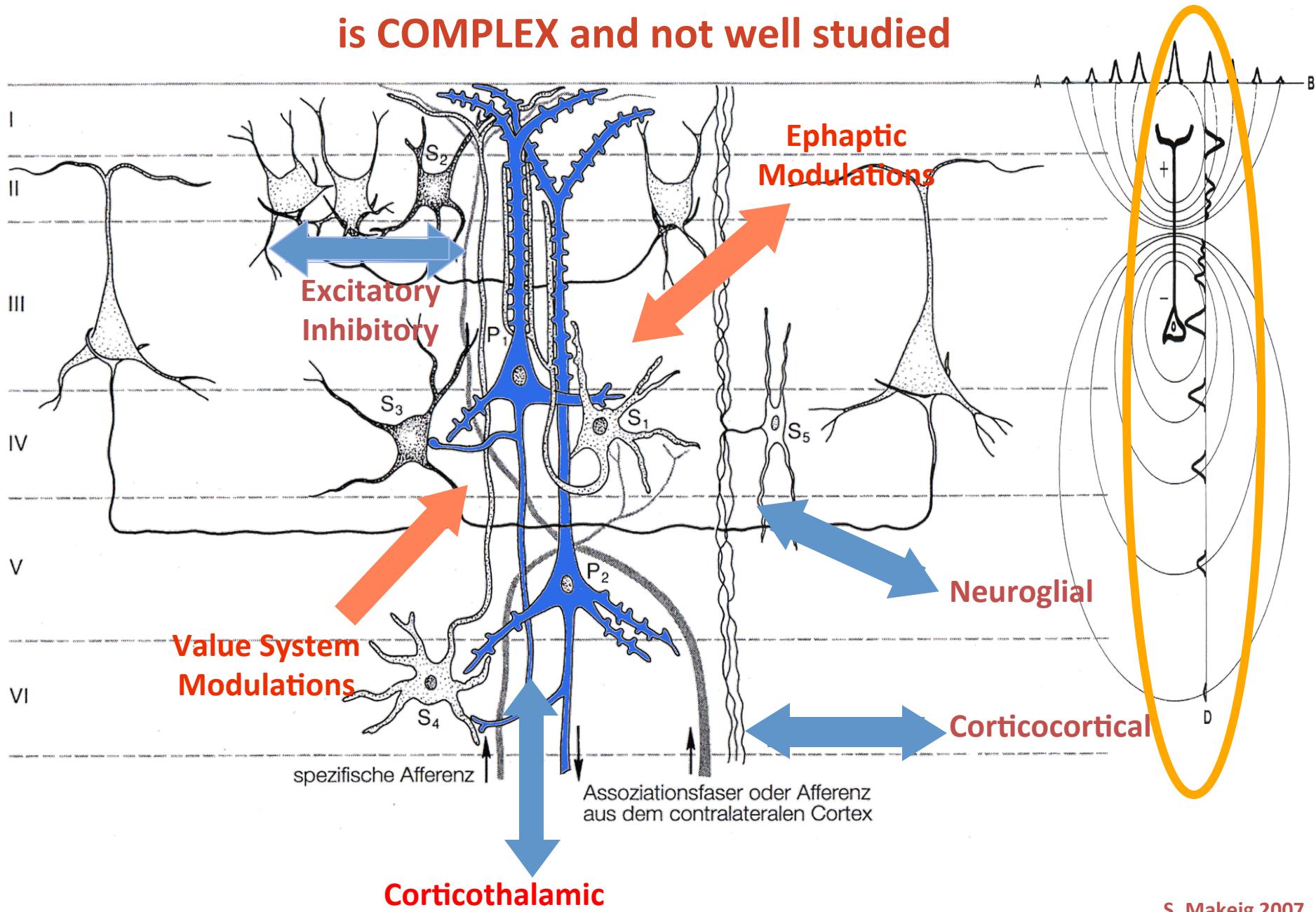
Larger



Smaller

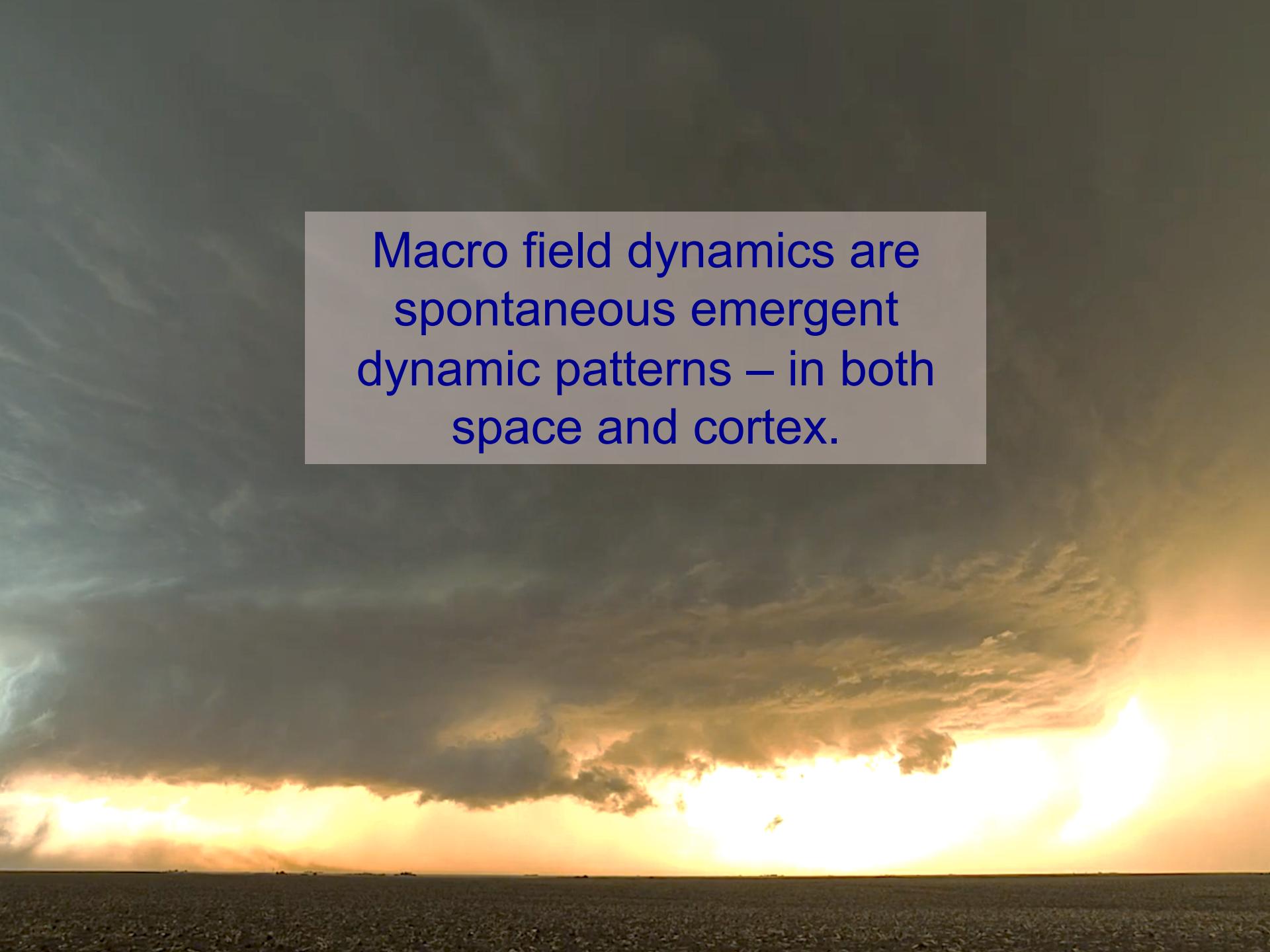


The generation and modulation of EEG is COMPLEX and not well studied





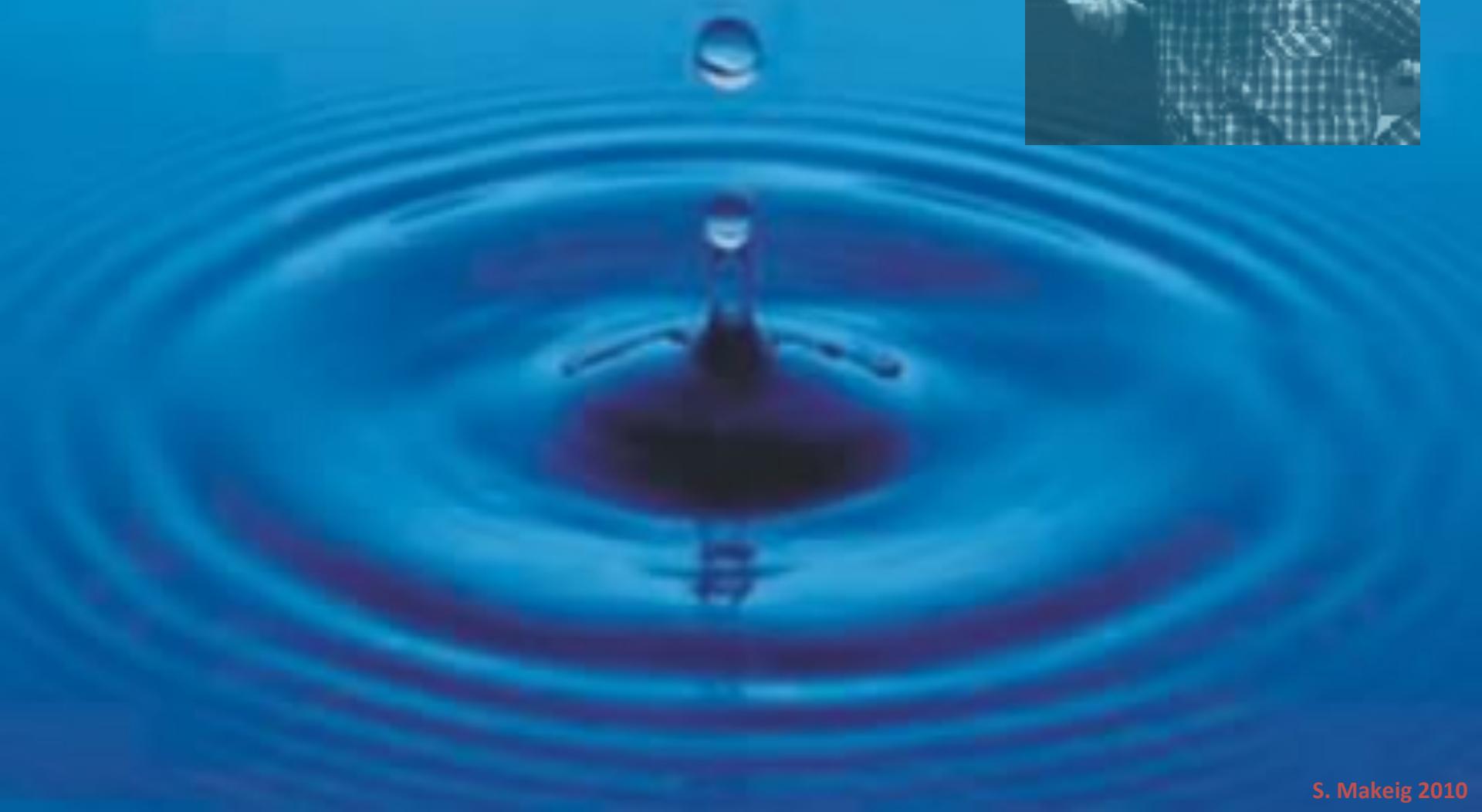
Macro field dynamics are spontaneous emergent dynamic patterns – in both space and cortex.

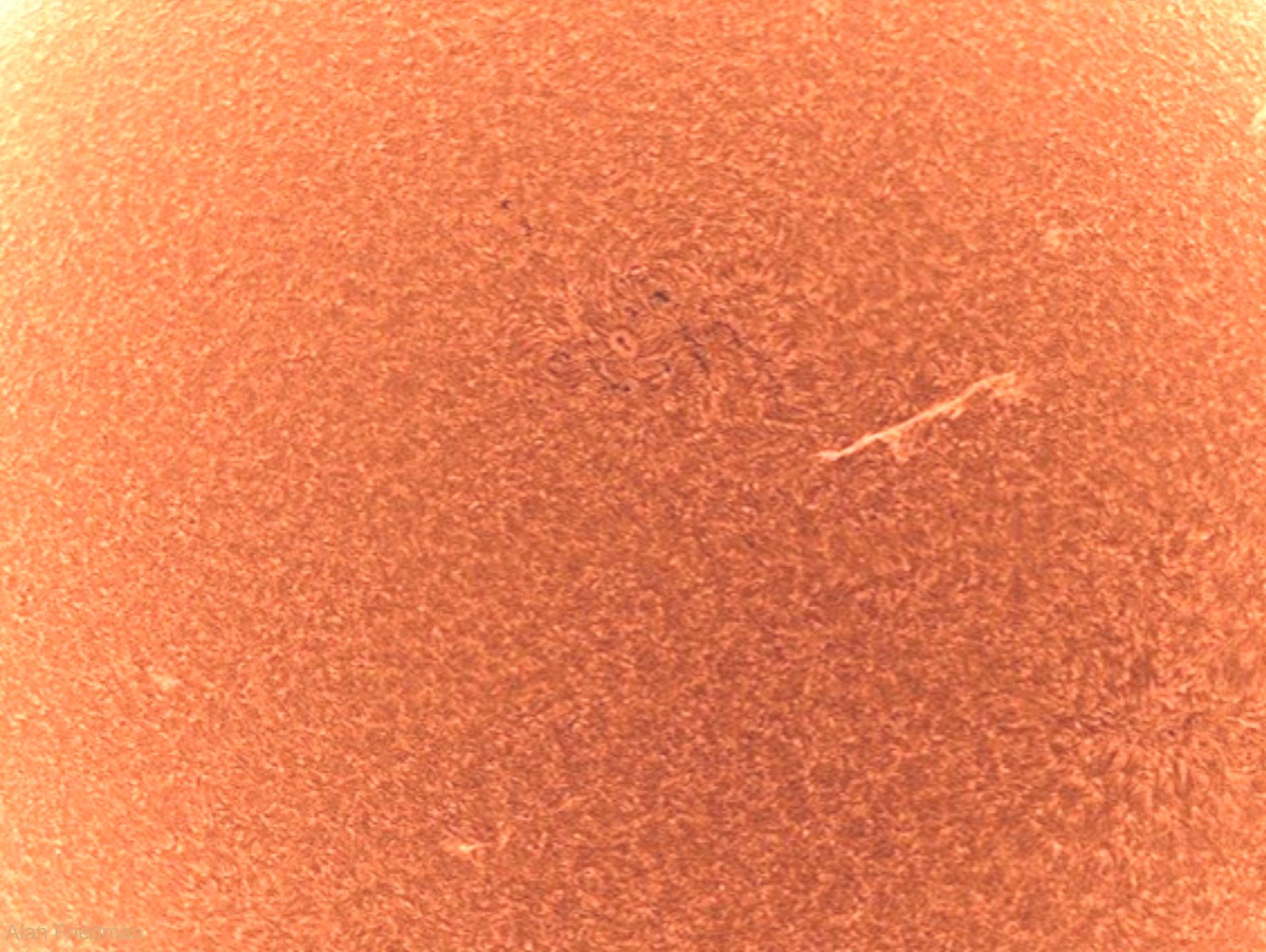
The background of the image shows a vast landscape under a dramatic sky at sunset or sunrise. The horizon is flat, likely a field, and the sky is filled with large, billowing clouds. The colors are a mix of deep blues and blacks on the left, transitioning to bright, intense oranges and yellows on the right where the sun is low on the horizon. The overall atmosphere is one of natural beauty and power.

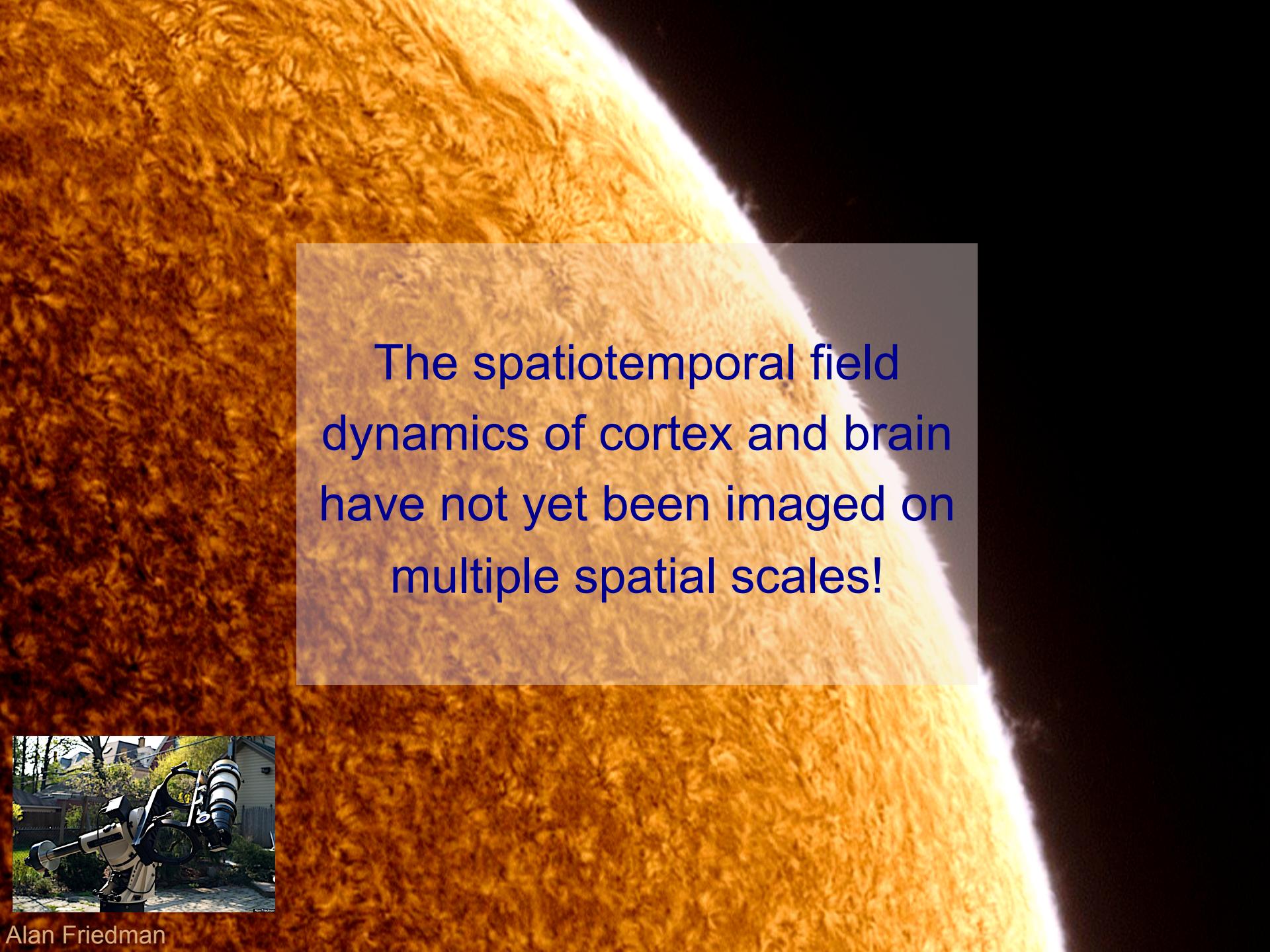
Macro field dynamics are
spontaneous emergent
dynamic patterns – in both
space and cortex.

Phase cones (Freeman)

Avalanches (Plenz)







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



Functional Brain Imaging

Hemodynamic imaging

= imaging local 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 cortical activity –
local spatial field coherence..

How to
measure/model
EEG?

MICRO

~1,000,000 GHz



SPIKES

LFP

EEG

BOLD

MACRO

?

BRAIN ← → BEHAVIOR
EXPERIENCE

Recorded !?

ERP
~0.001 Hz

RT

~1 Hz

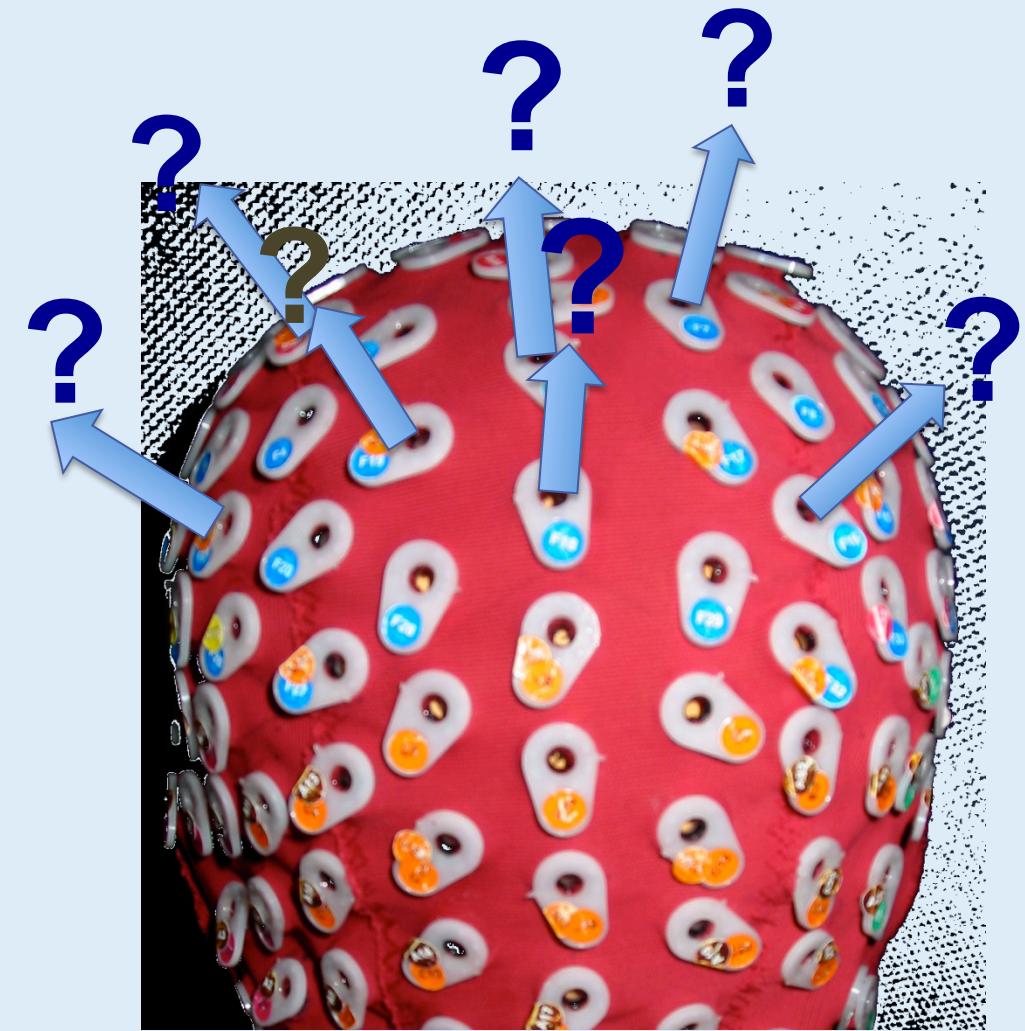
~1 MHz

Brain EEG vs Scalp EEG

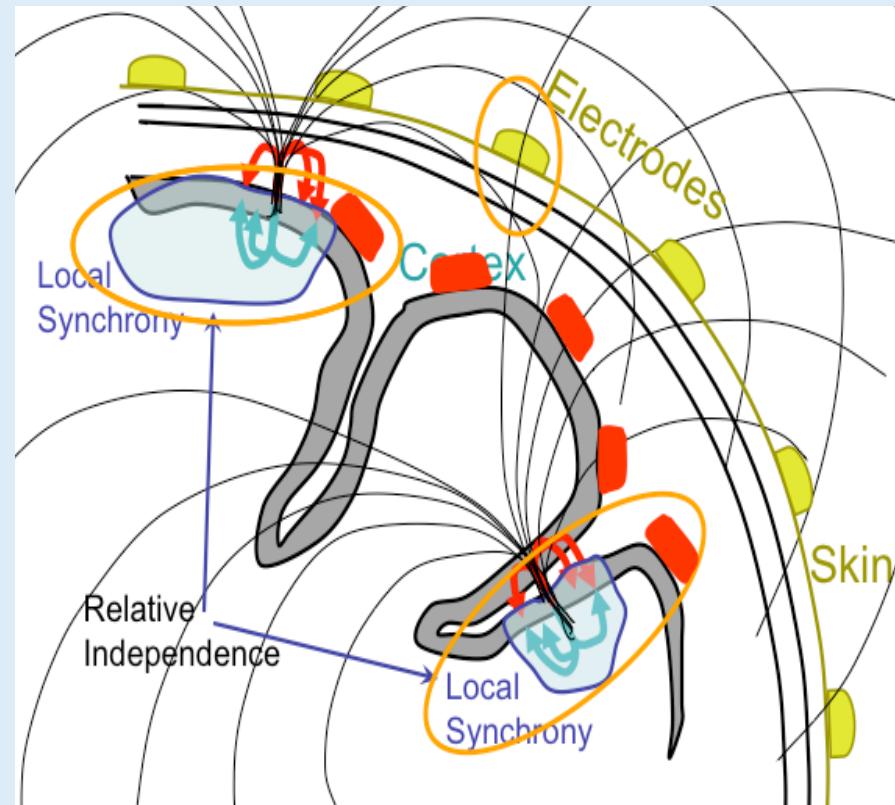
scalp signals \neq source signals !

Skull

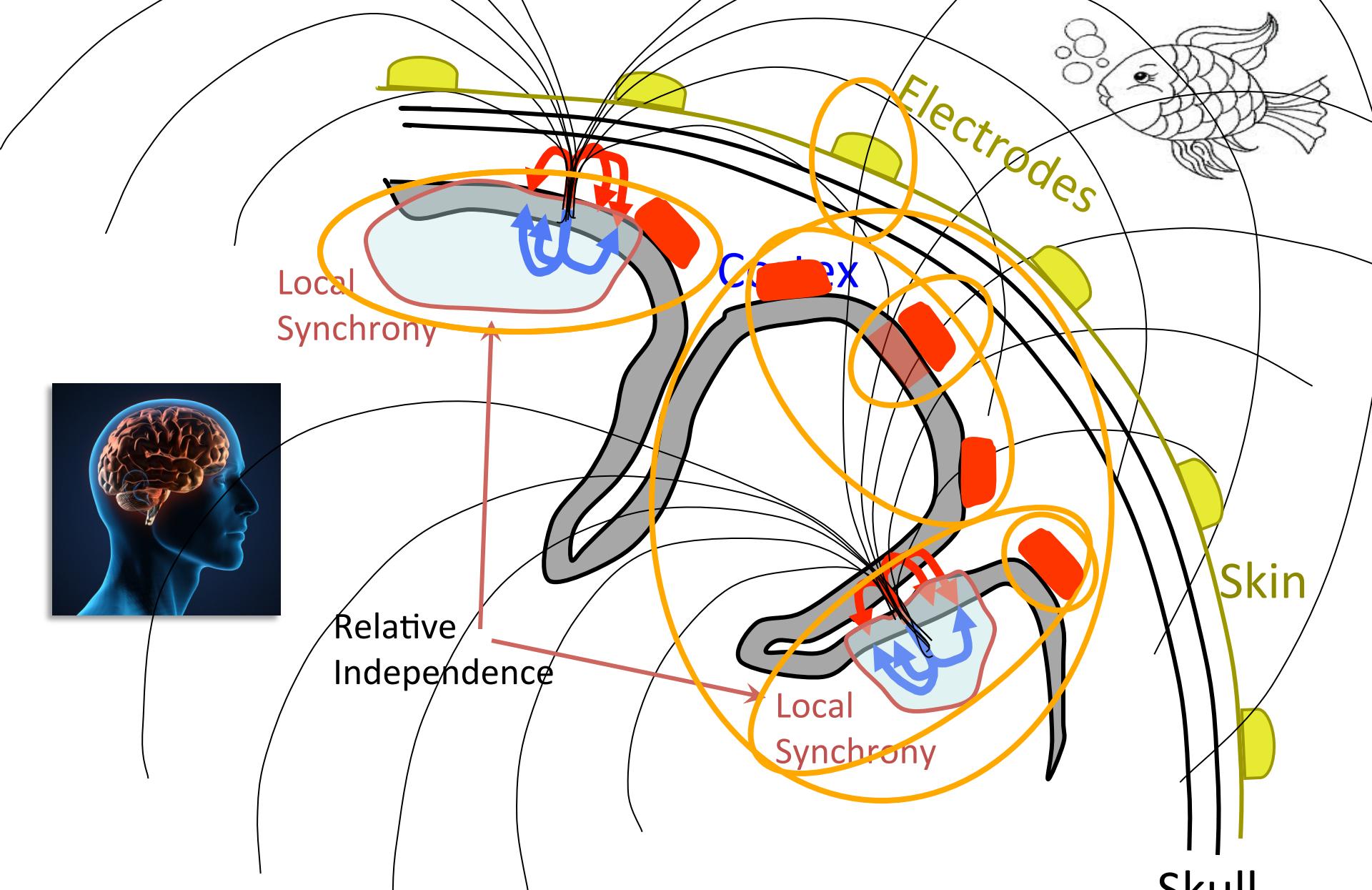
Naïve 2-D interpretation of EEG signals?



Cortical EEG signal projection patterns as point processes

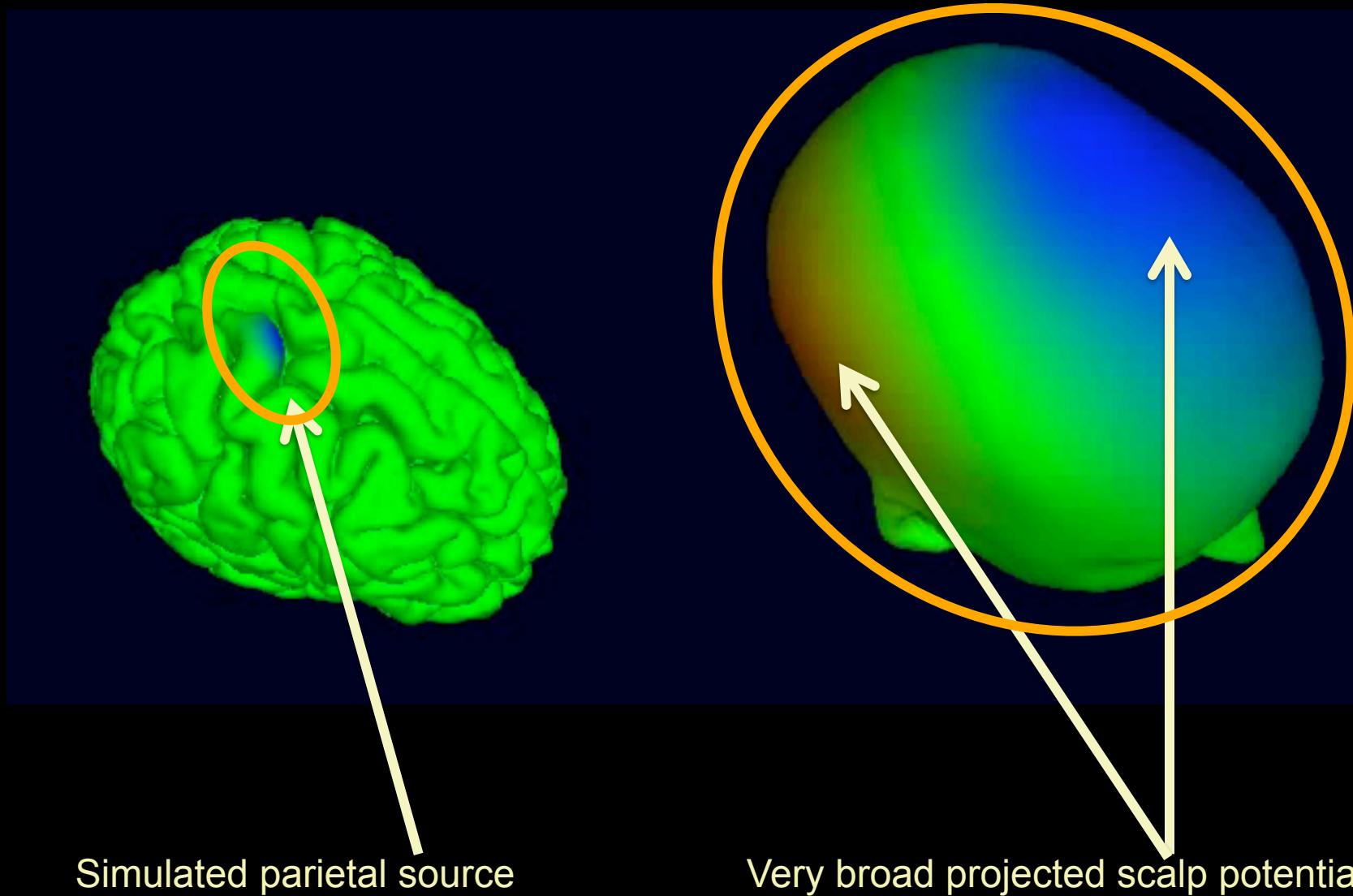


Cortical source current volume conduction patterns (cartoon)

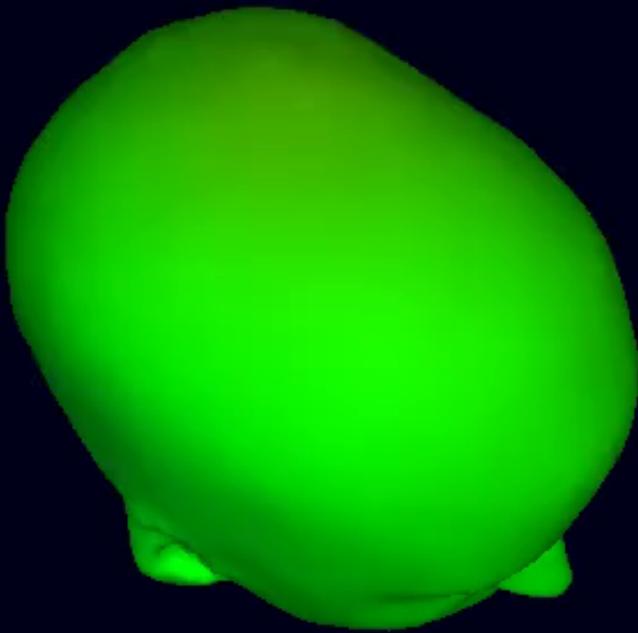
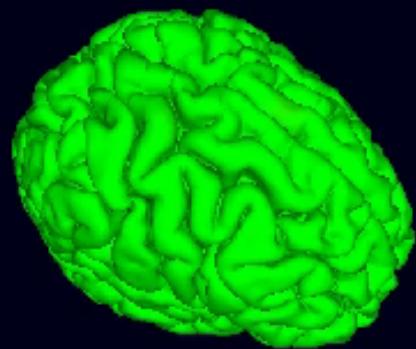


scalp signals \neq source signals !

The very broad EEG point-spread function



Effects of volume conduction on scalp EEG

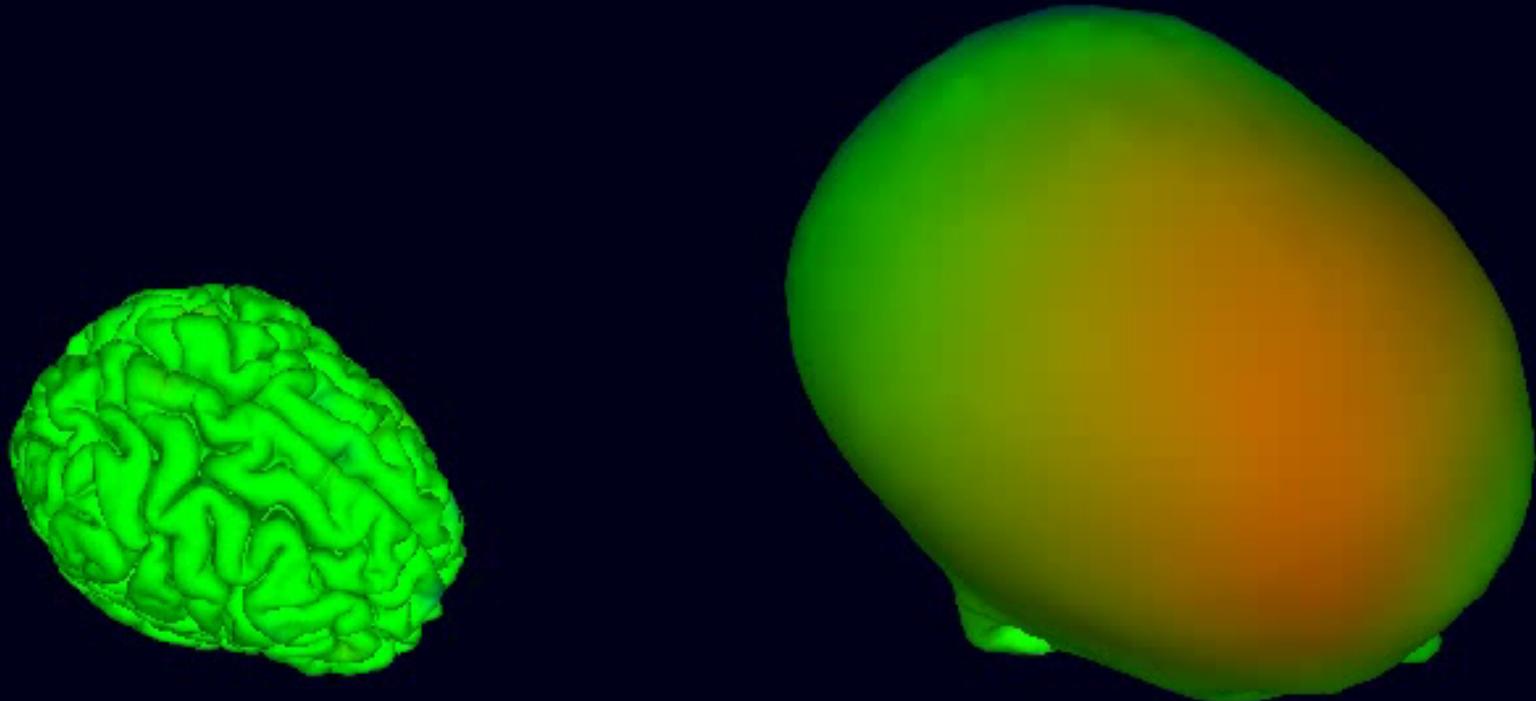


Simulated EEG summing cortical alpha band source activities (animated at 1/5th real time)

Cortical sources

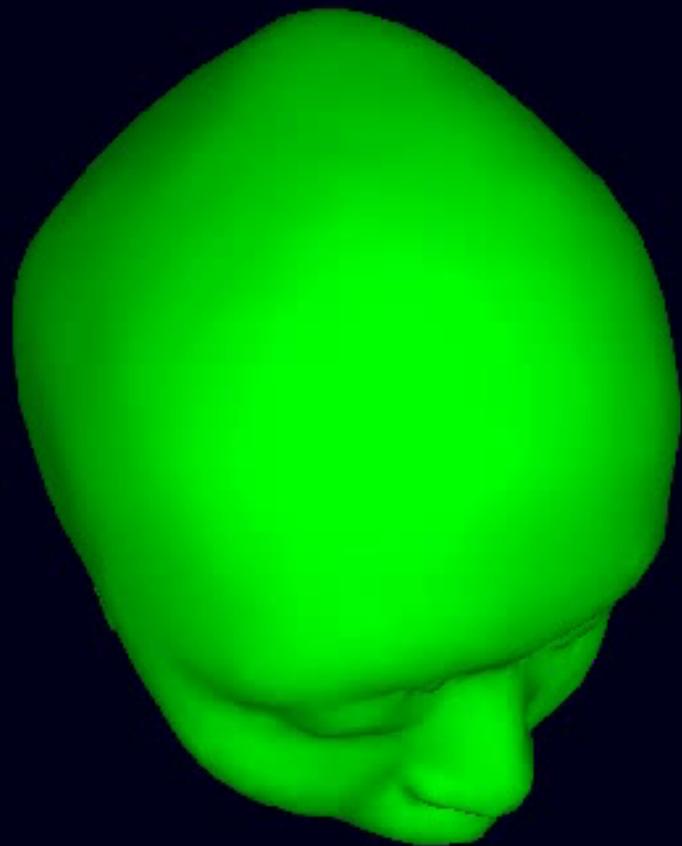
**Their summed
scalp projection**

The very broad EEG point-spread function



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

Effects of non-brain artifacts on scalp EEG



Without non-brain sources



Including non-brain sources

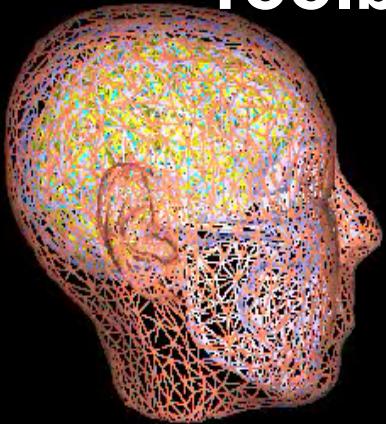


Electromagnetic source localization using realistic head models

Neuroelectromagnetic Forward Head Modeling

Solve the forward problem using realistic head models (BEM)

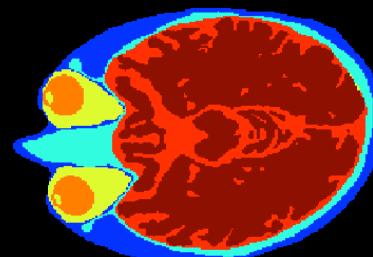
Toolbox (NFT)



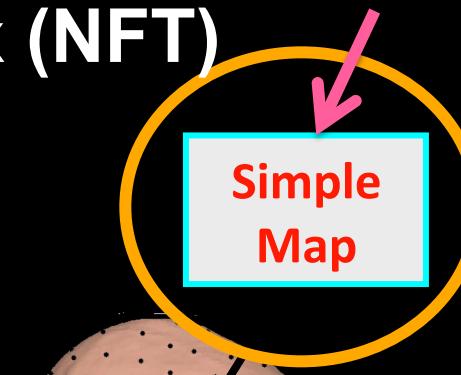
Mesh generation



MRI



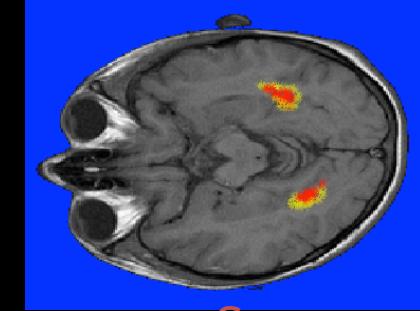
Segmentation



Simple
Map



Sensor Co-
Registration



Source
Image

Signal
Processing



EEG/MEG

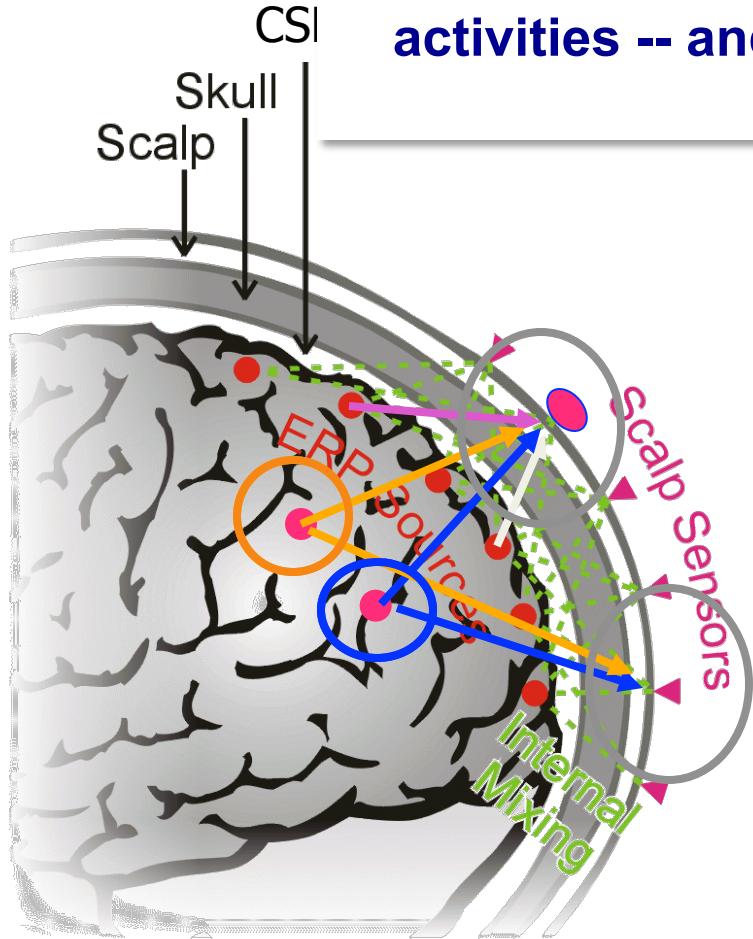


Information based signal processing

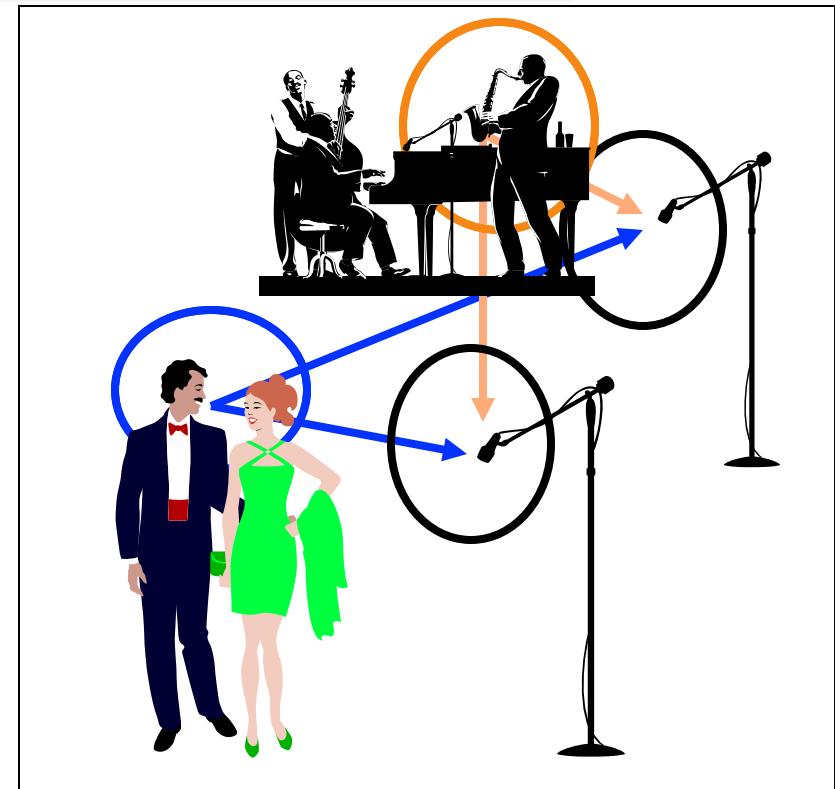
Blind EEG Source Separation by Independent Component Analysis



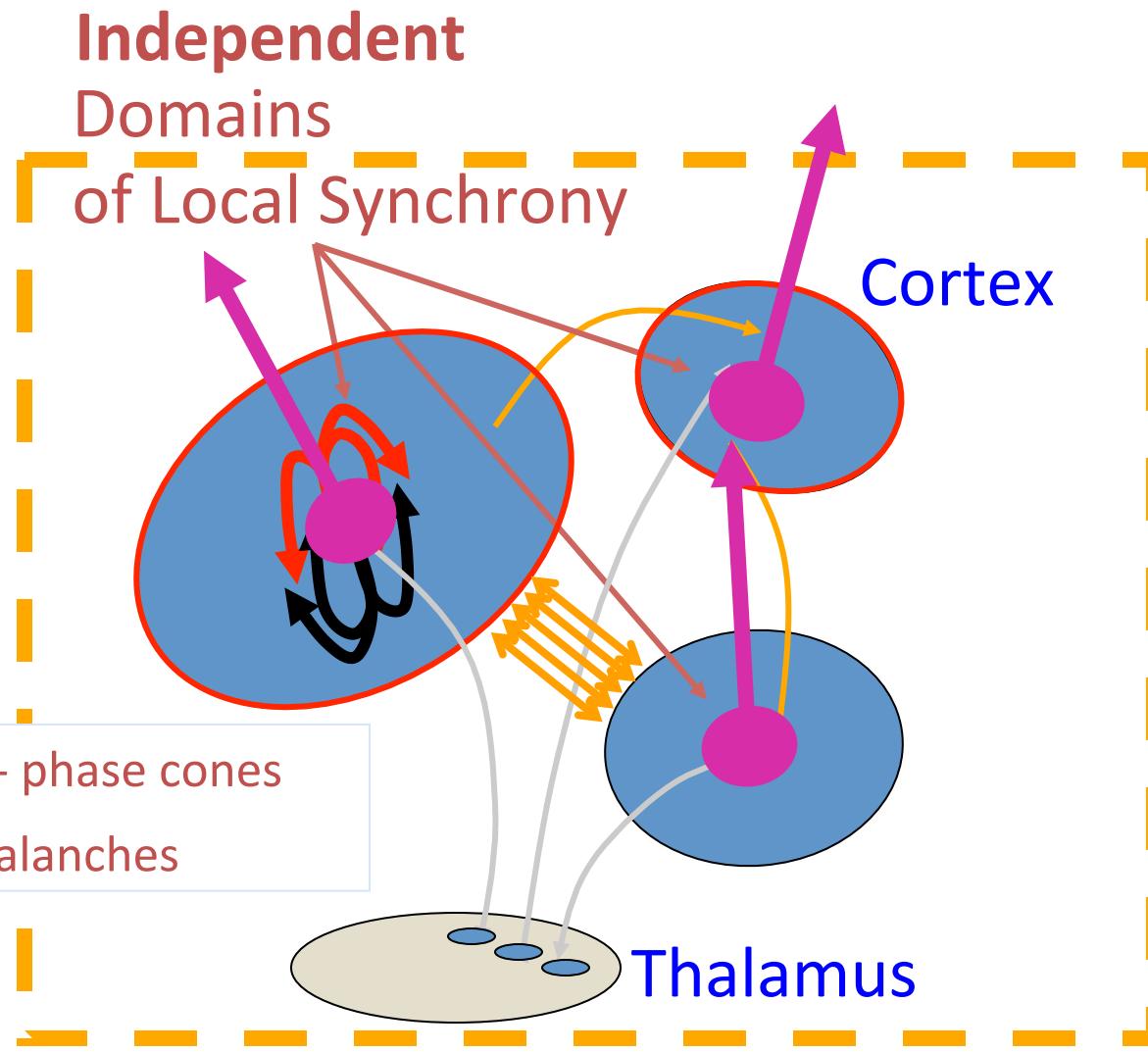
Tony Bell,
developer of
Infomax ICA



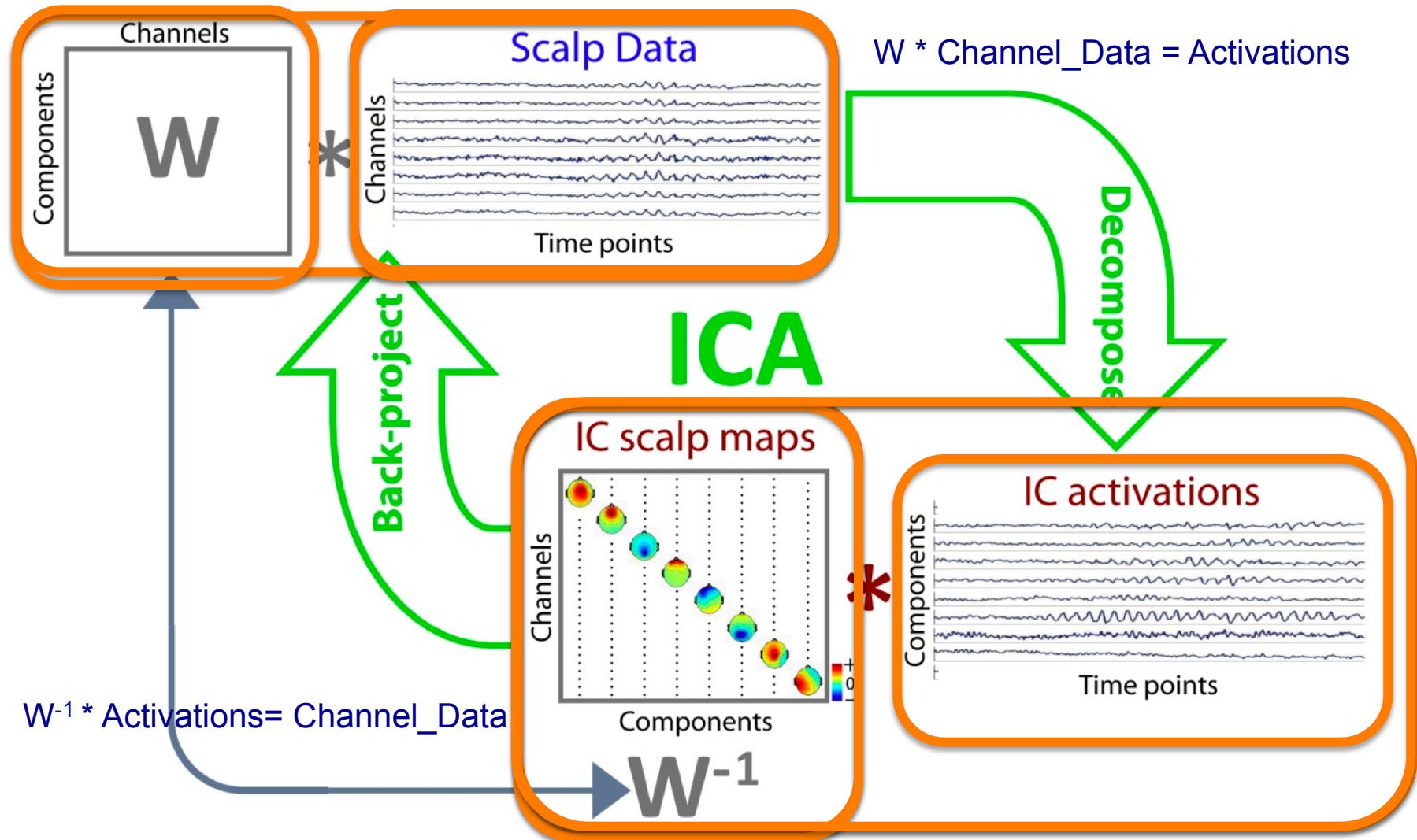
ICA can find distinct EEG source activities -- and their 'simple' scalp maps!



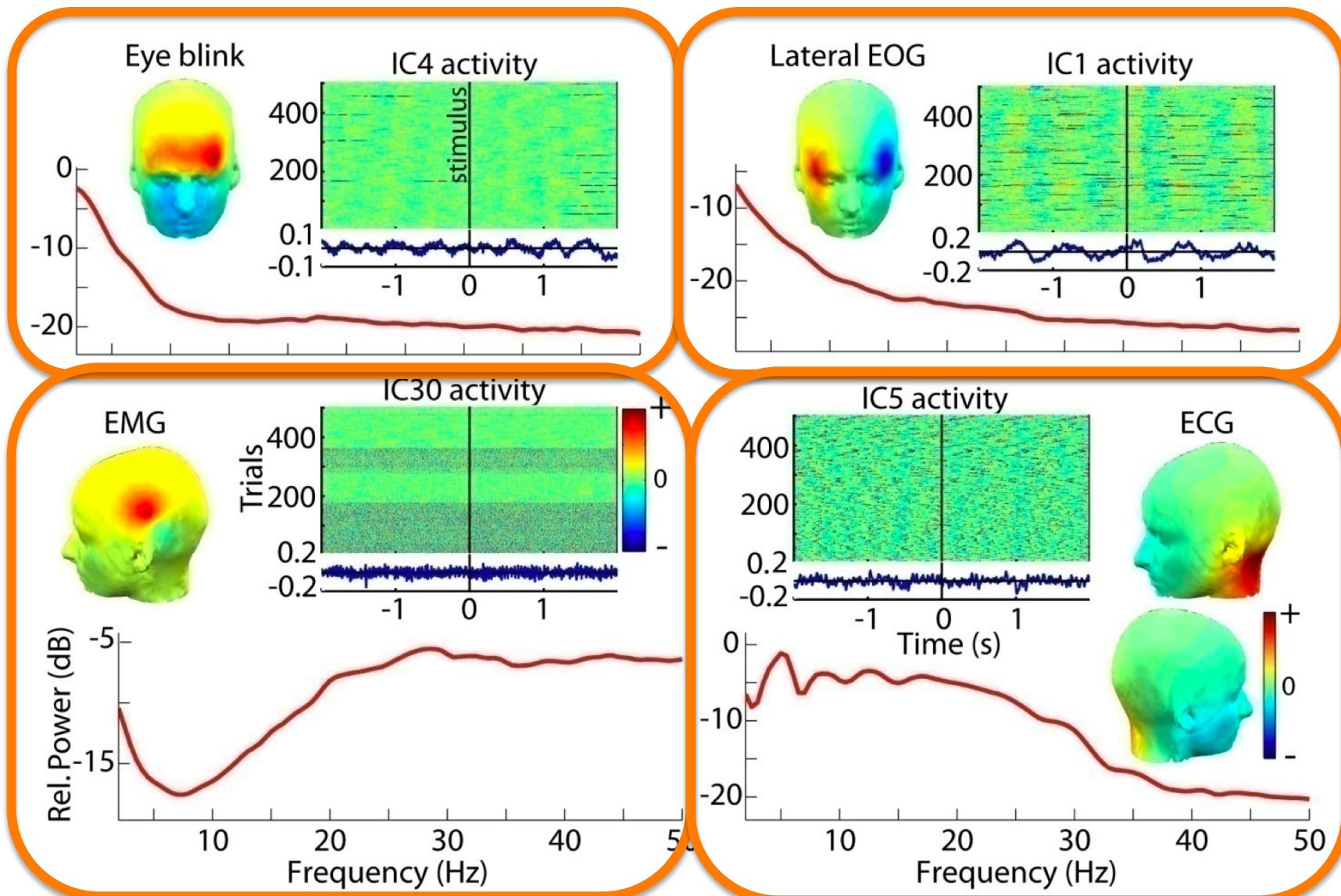
Are EEG source signals (near) independent?



ICA is a linear data decomposition method

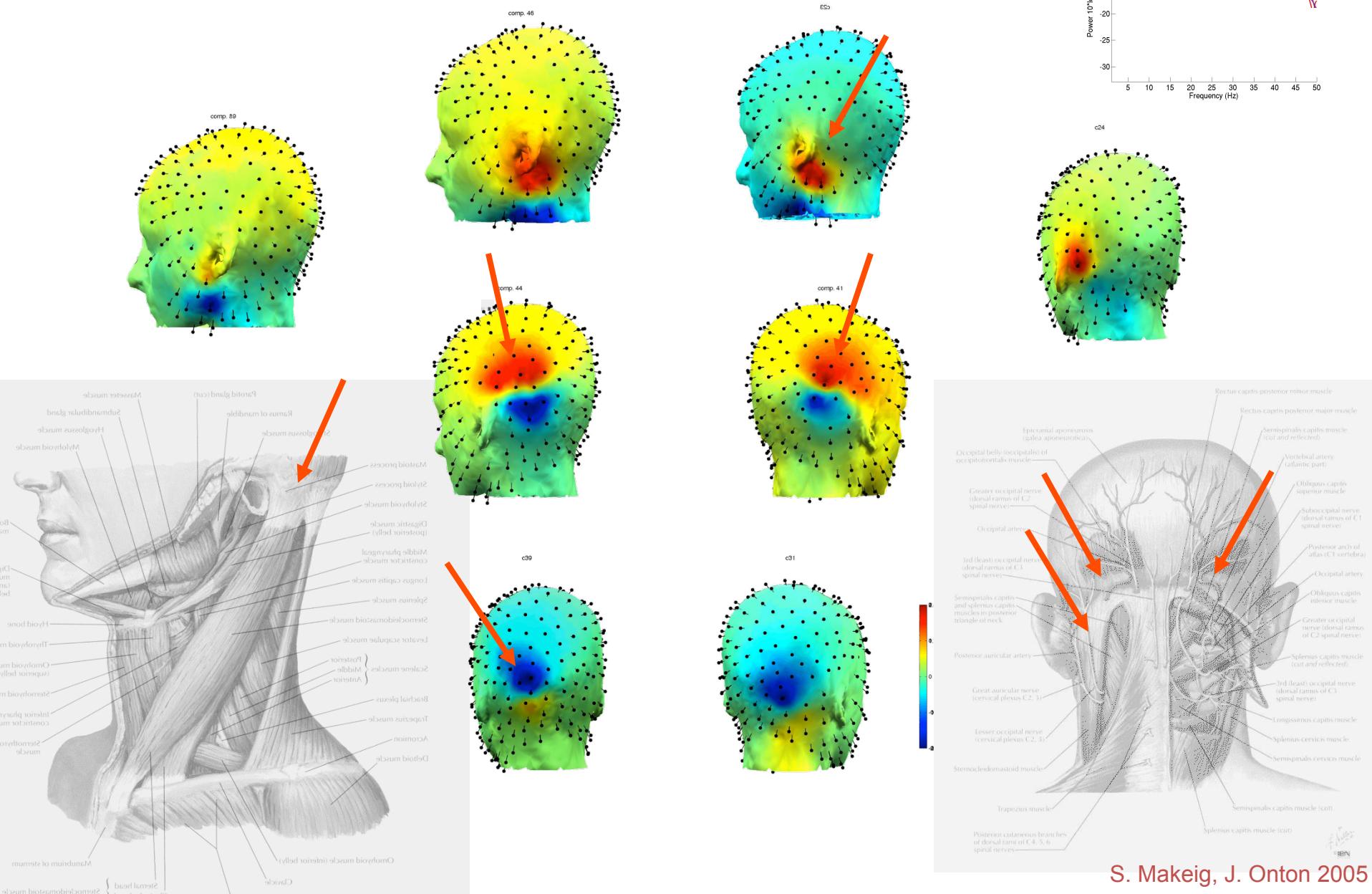


ICA finds Non-Brain Independent Component (IC) Processes ...

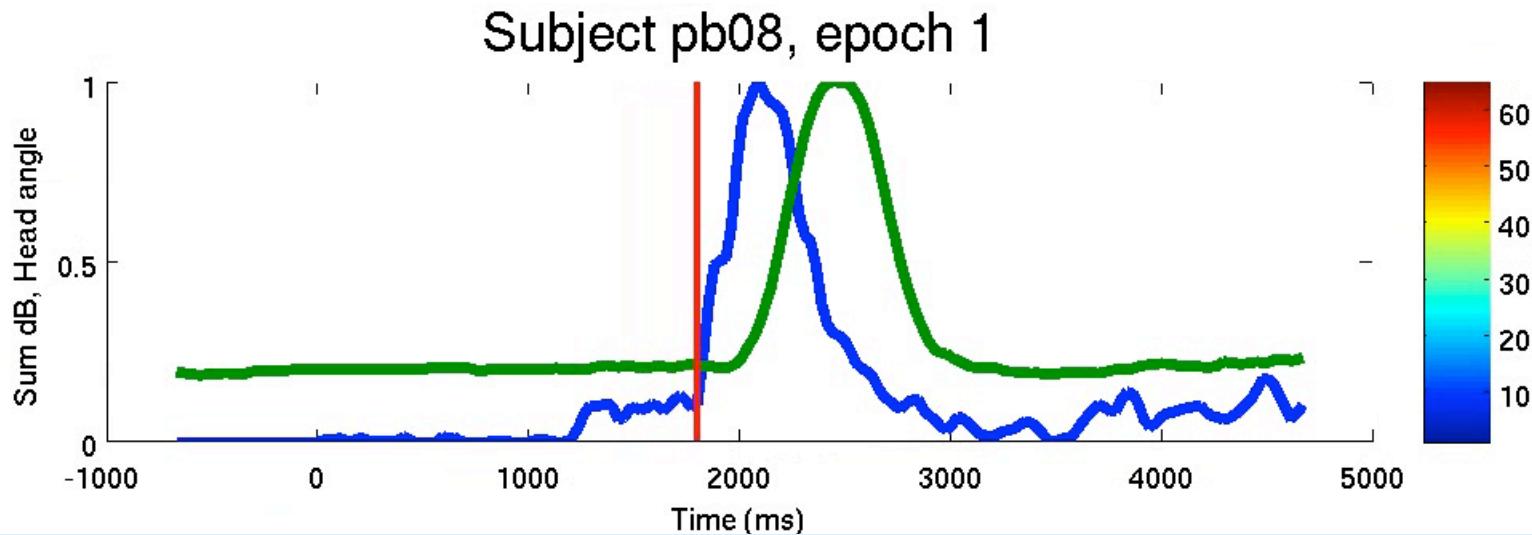
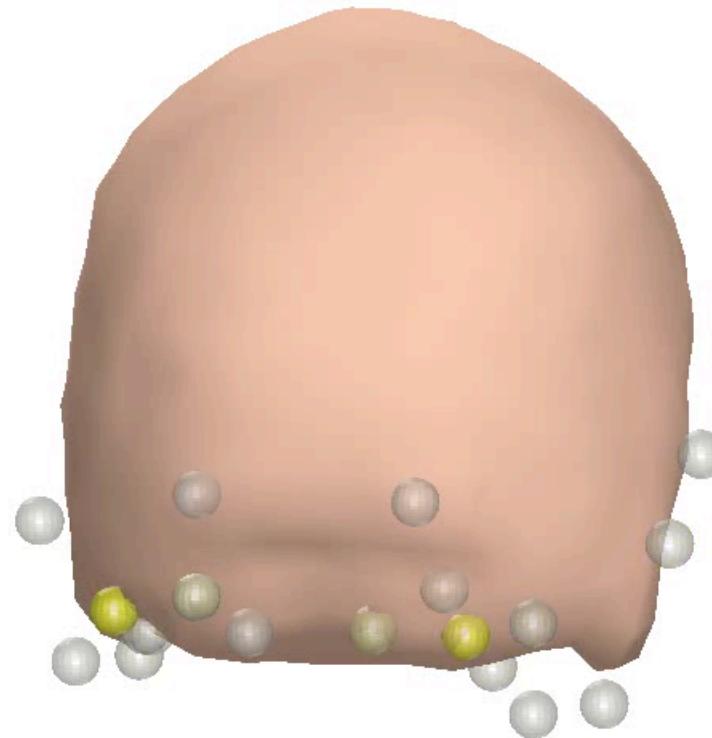


... separates them from the remainder of the data ...

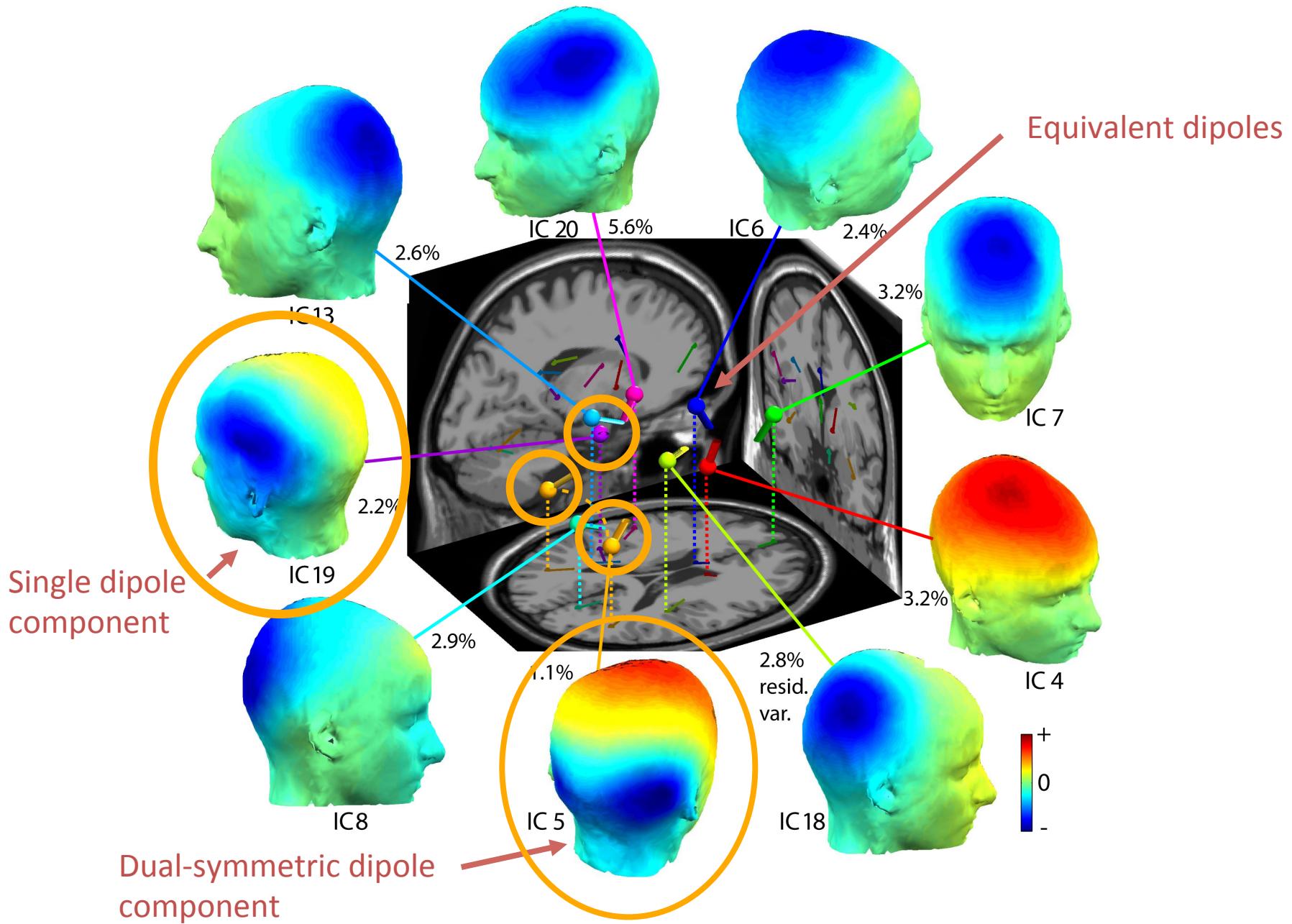
Independent muscle signals

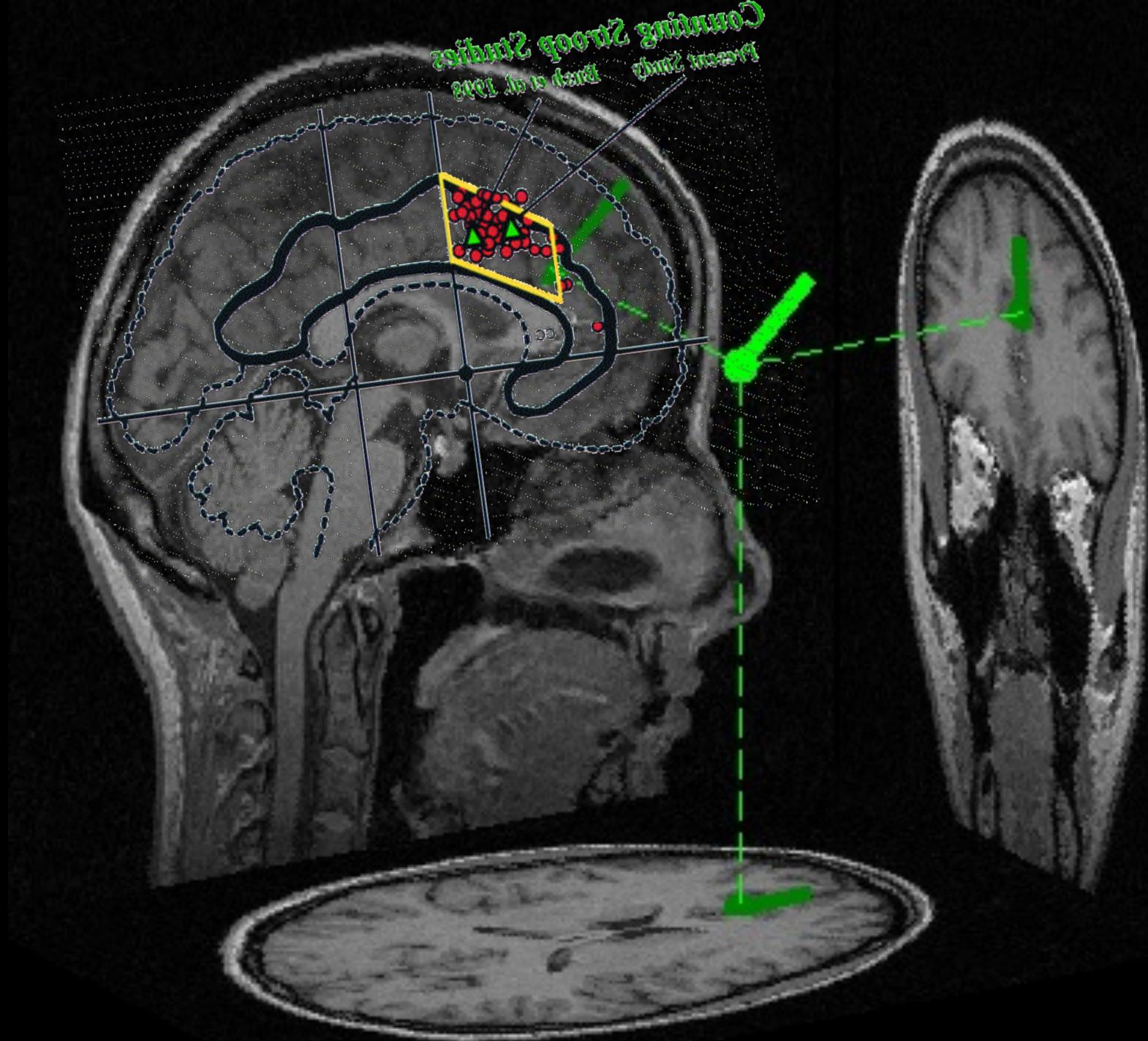


Distributed neck muscle & movement dynamics



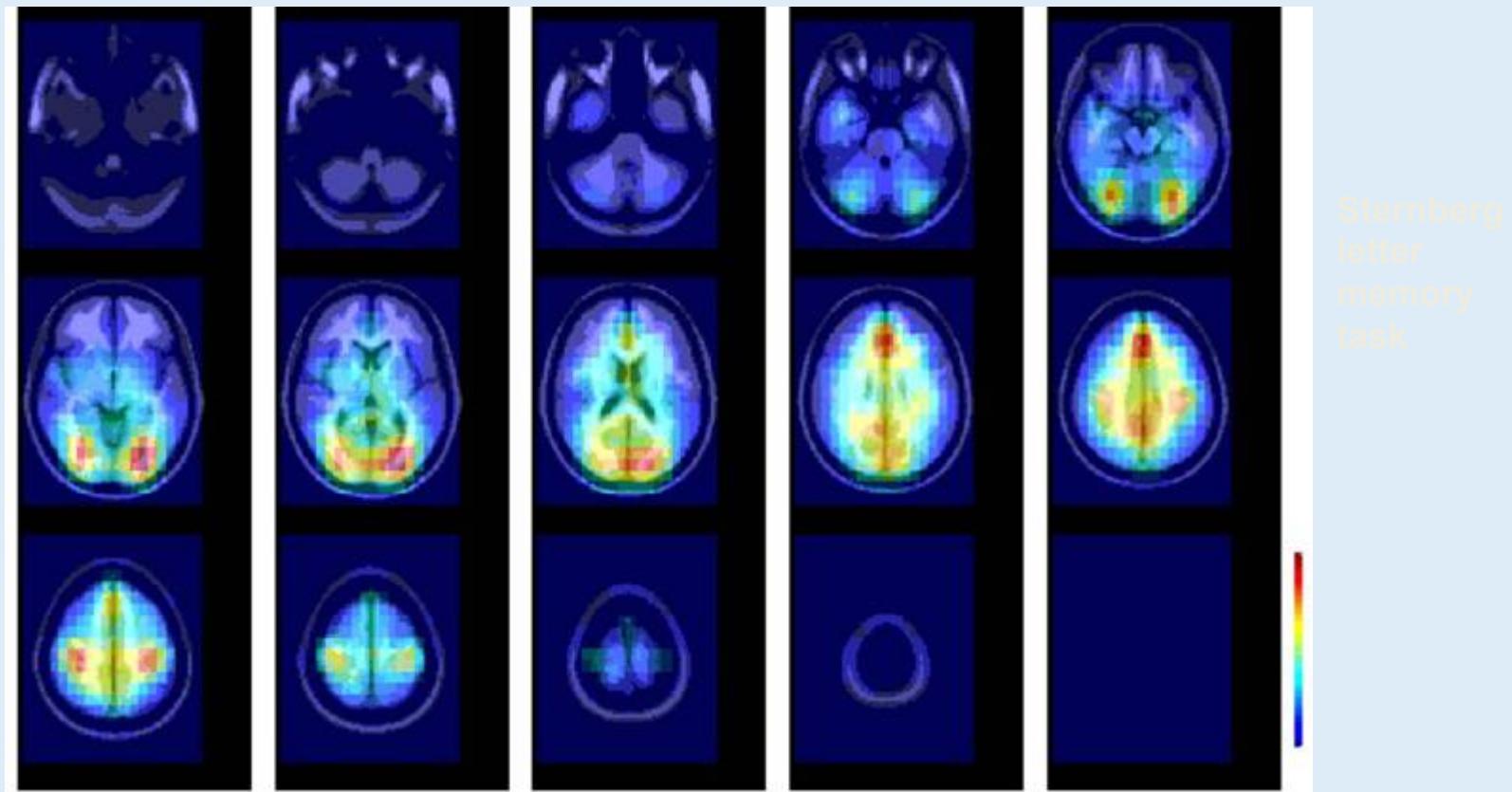
... and also separates cortical brain IC processes





Equivalent dipole density

Visual Working Memory

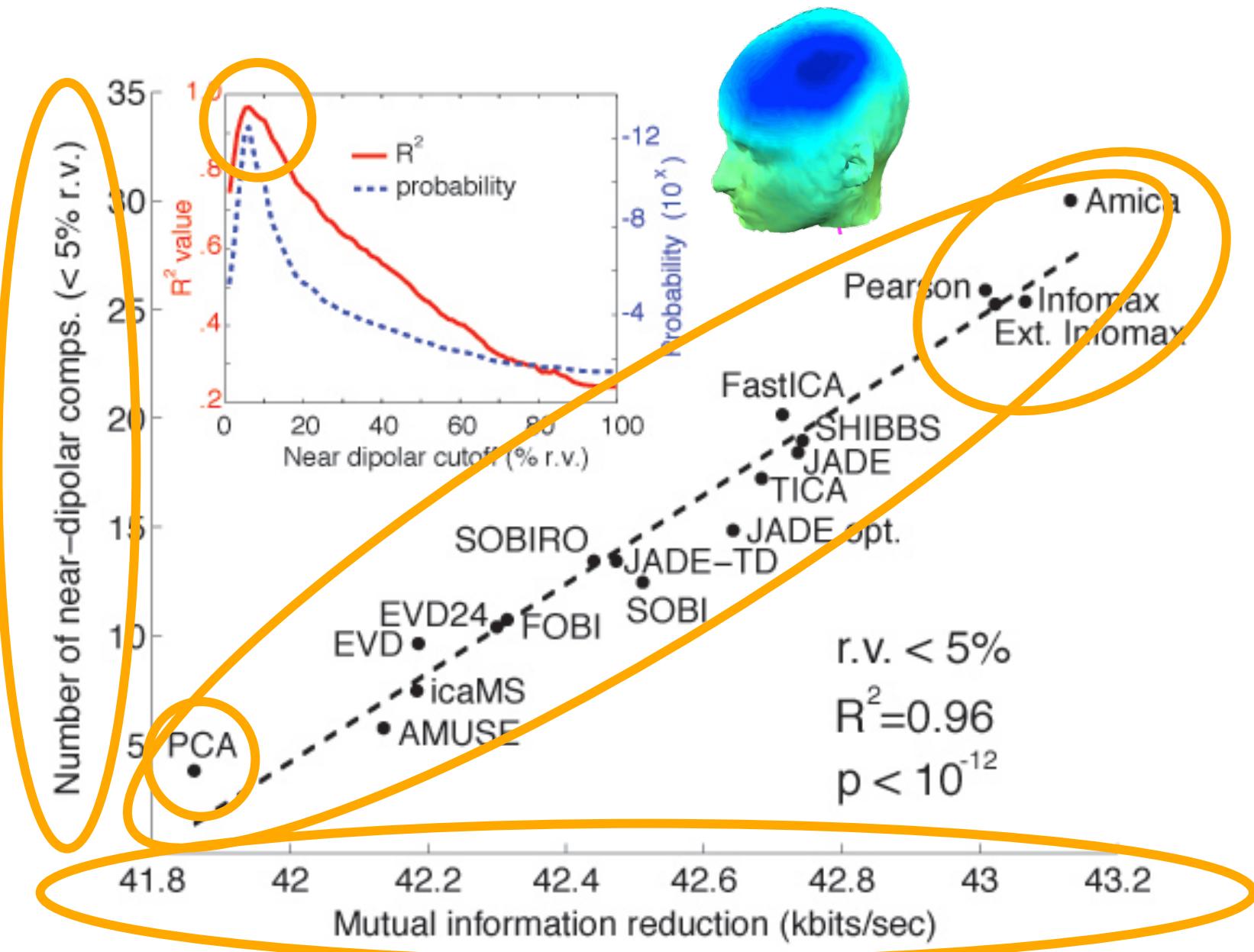


Important Result

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 cortical (or else non-brain, artifactual) source process.

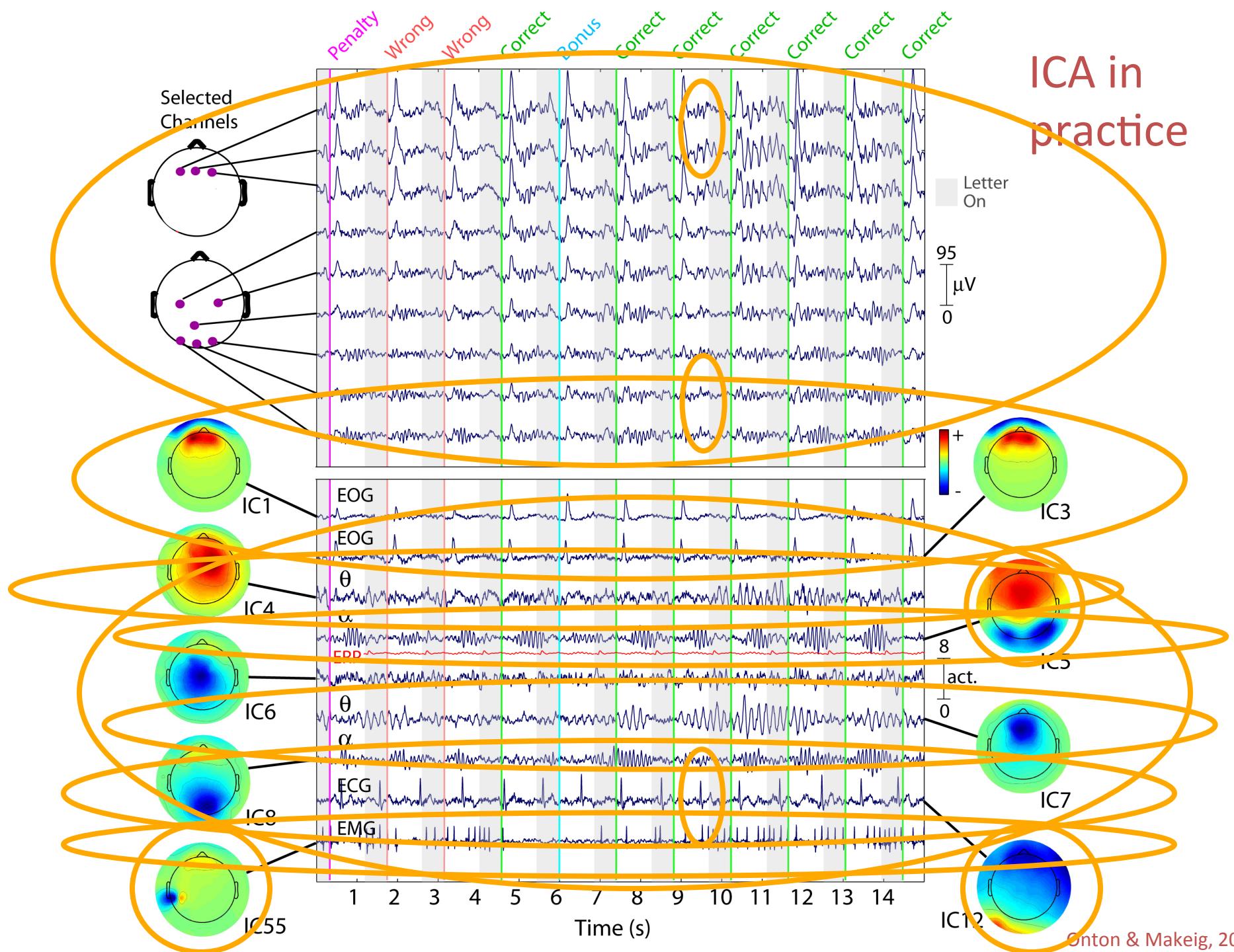
Delorme et al., *PLOS One*, 2012

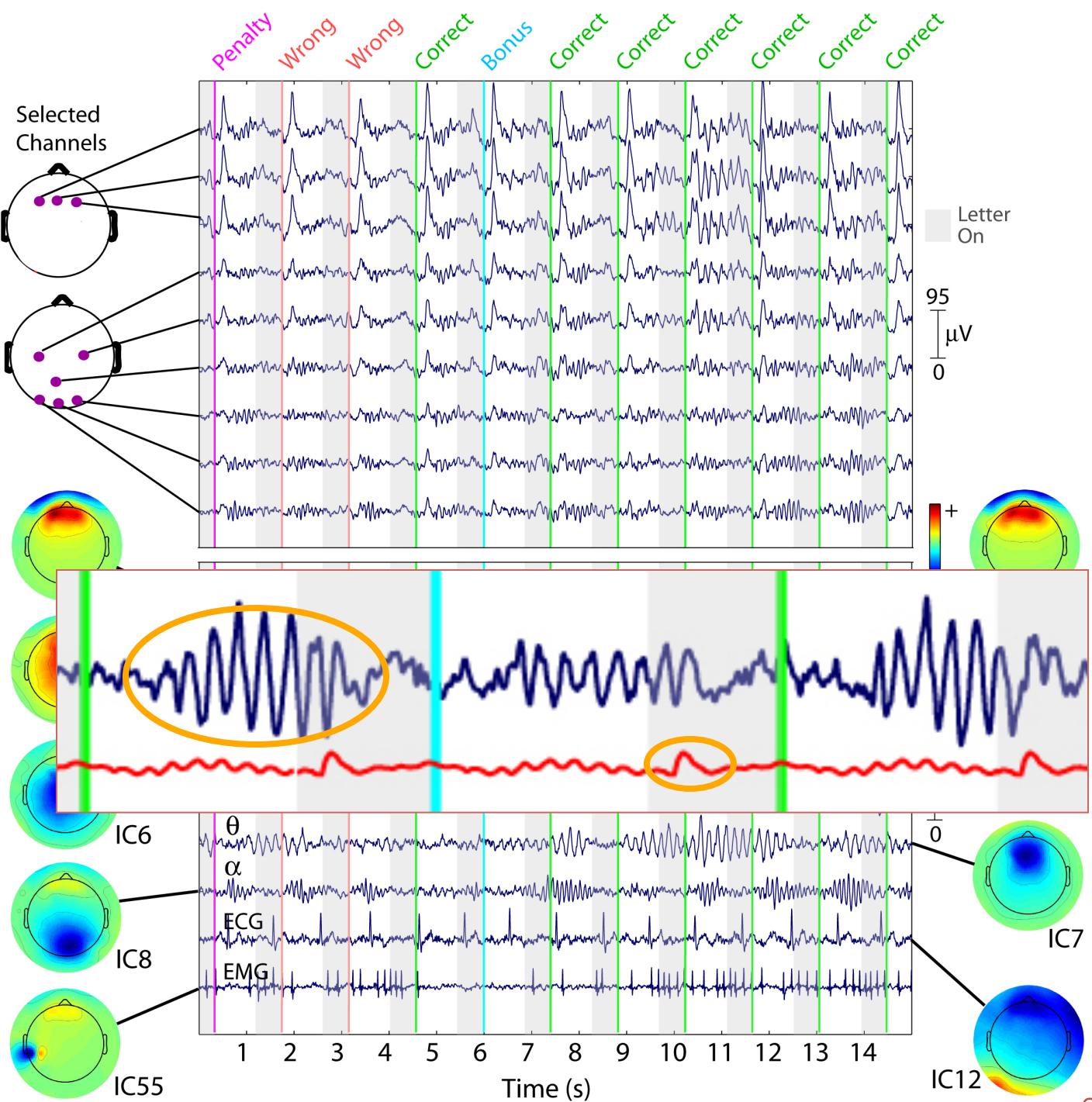


Delorme et al., *PLOS One*, 2012

S. Makeig, 2011

ICA in practice





**Who
am I?**