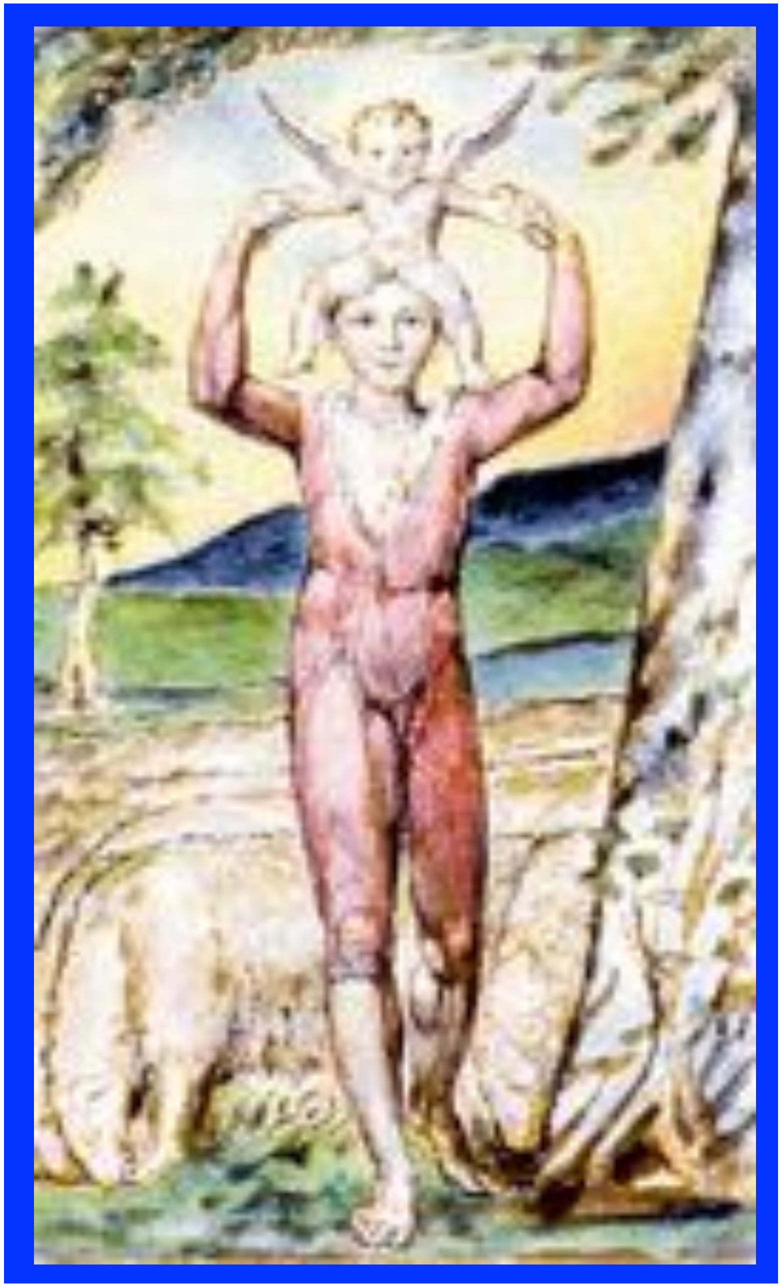


Mining EEG brain dynamics

Swartz Center for Computational Neuroscience

Scott Makeig

Institute for Neural Computation

University of California San Diego

NIAC Seminar

Washington University, St. Louis

September, 2012

Embodied Agency

Brain processes

have evolved and function

*to optimize the **outcome***

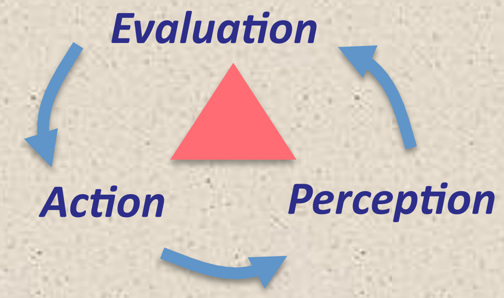
*of the **behavior***

the brain organizes

in response to

perceived challenges

and opportunities.



Brains meet the challenge of the moment!

Functional Brain Imaging History

Some human brain imaging milestones

EEG era 1

1926 ~1st human EEG recording

1938 1st (analog) EEG spectral analysis

ERP era

1962 ~1st computer ERP averaging (CAT) 4

1972 ~1st magnetoencephalogram (MEG)

fMRI era 16

1993 1st fMRI BOLD recordings

1993 1st broadband ERSP 32

1995 1st multisource EEG filtering by ICA

256

fEEG / BCI / MoBI era …

2009 ~1st commercial dry-electrode EEG toys 1

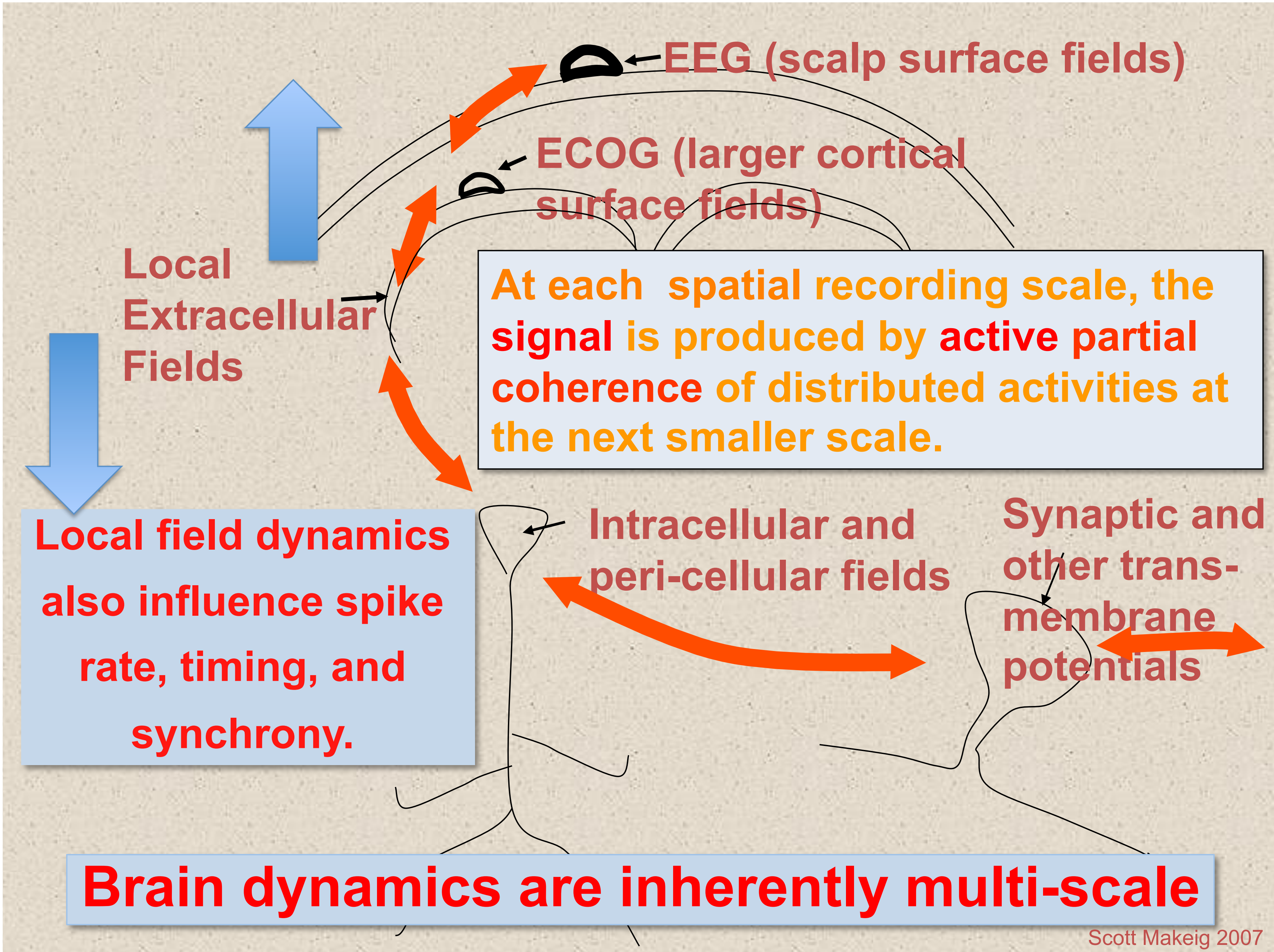
2011 ~1st MoBI Laboratory 14

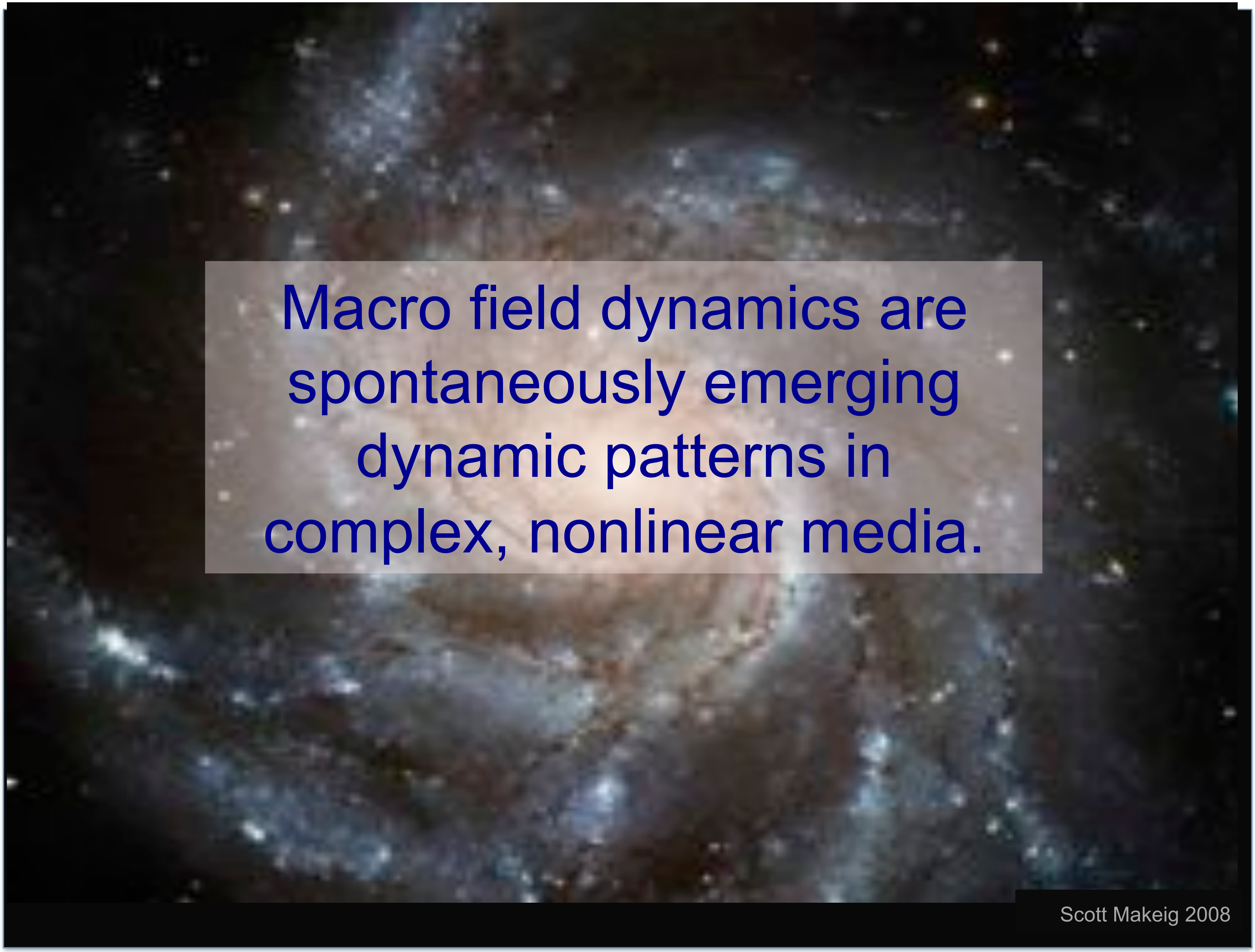
2012 ~1st Online 3-D mobile phone apps 80

10000

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).

S. Makeig 2011


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.
Local field dynamics also influence spike rate, timing, and synchrony.
Intracellular and peri-cellular fields
Synaptic and other trans-membrane potentials
Brain dynamics are inherently multi-scale
Scott Makeig 2007


Macro field dynamics are spontaneously emerging dynamic patterns in complex, nonlinear media.
Scott Makeig 2008

Phase cones (Freeman)

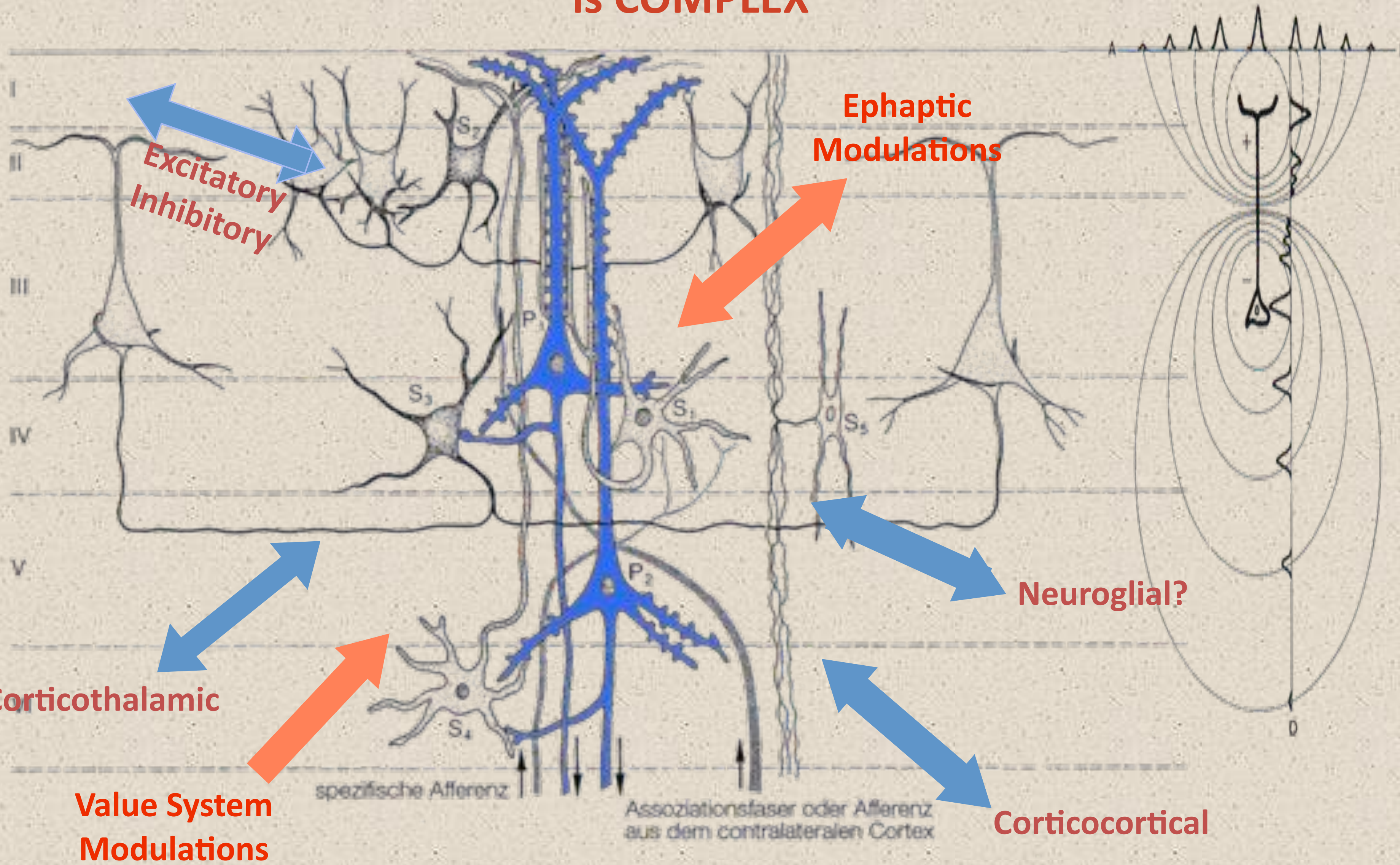
Avalanches (Beggs & Plenz)

S. Makeig 2007

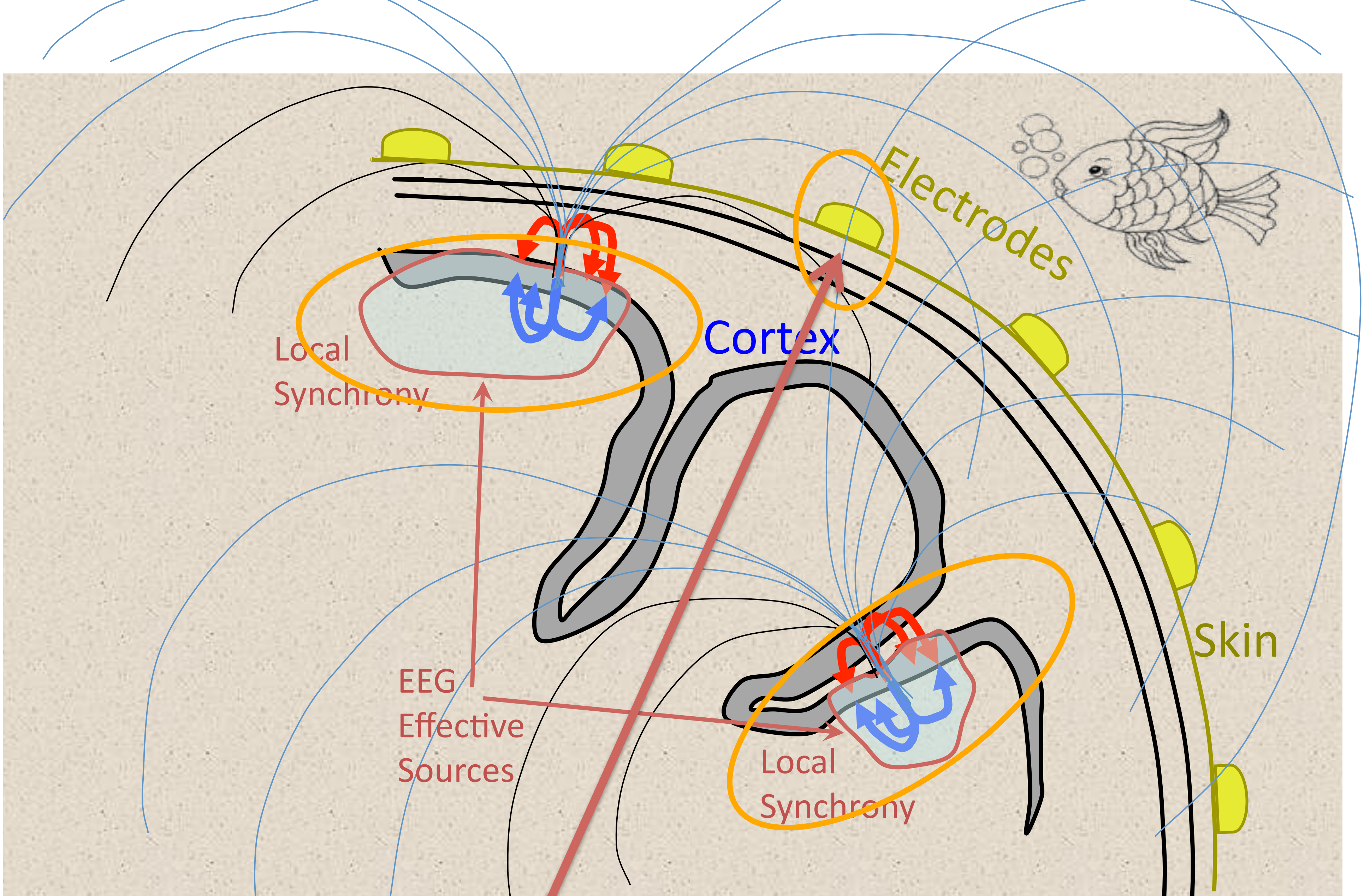
The spatiotemporal field dynamics of cortex have not yet been imaged simultaneously on multiple spatial scales!

Alan Friedman

The generation and modulation of EEG / LFP is COMPLEX

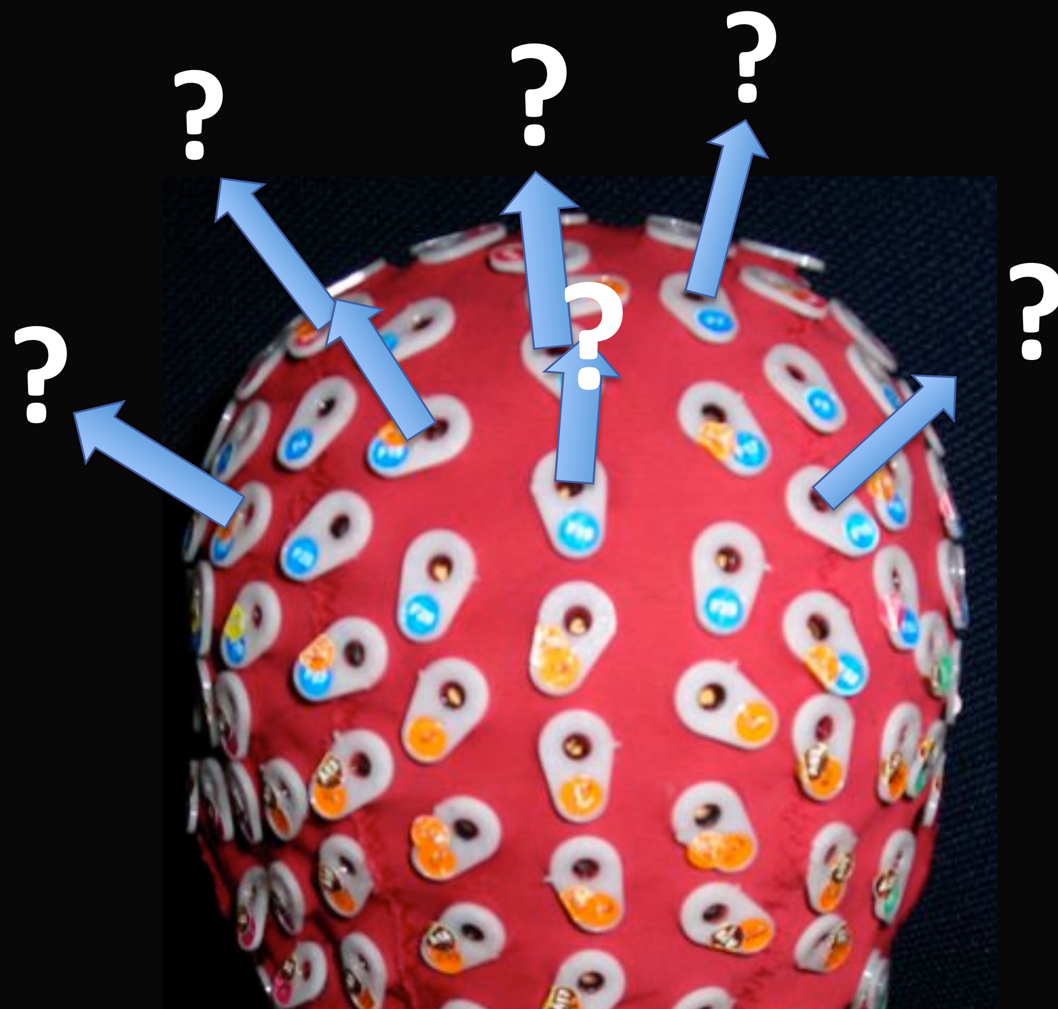


S. Makeig 2007



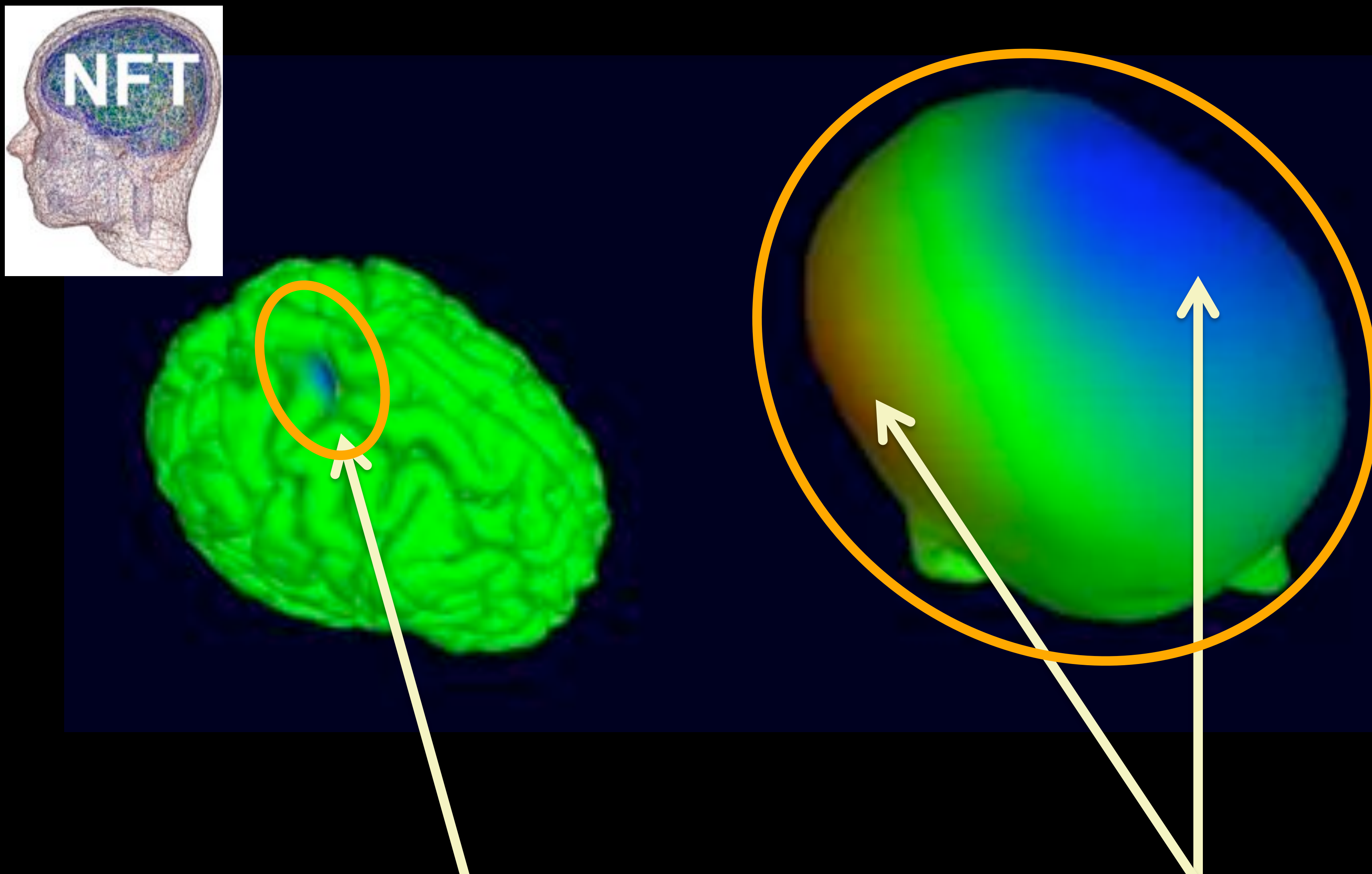
Each scalp EEG data channel sums the projected activities of multiple brain (and non-brain) source processes.

S. Makeig 2007



2-D Interpretation of Scalp EEG Signals ?

The very broad EEG point-spread function



Akalin Acar & Makeig 2010

The very broad EEG point-spread function

This animation is available for YouTube viewing at

http://sccn.ucsd.edu/

and for download at

http://sccn.ucsd.edu/eeglab/TwoSourceEEG12.mp4

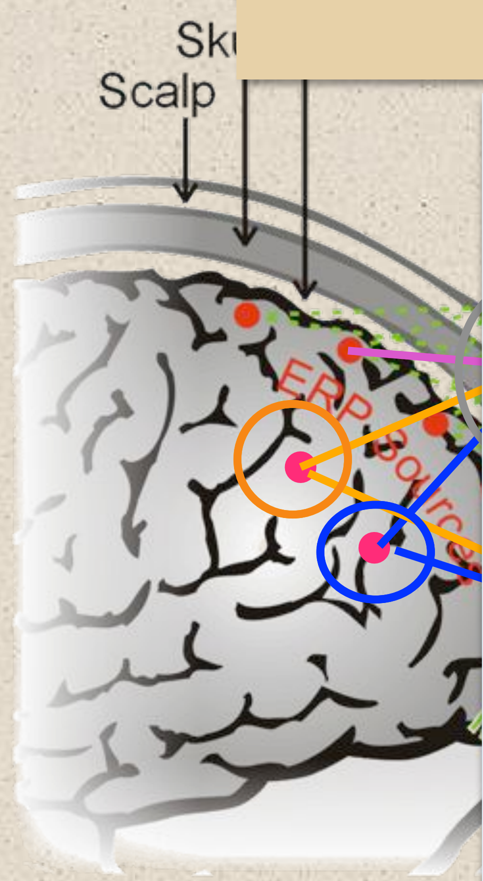
Simulated cm^2-scale multi-source activity, and its EEG projection

Akalin Acar & Makeig 2010

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

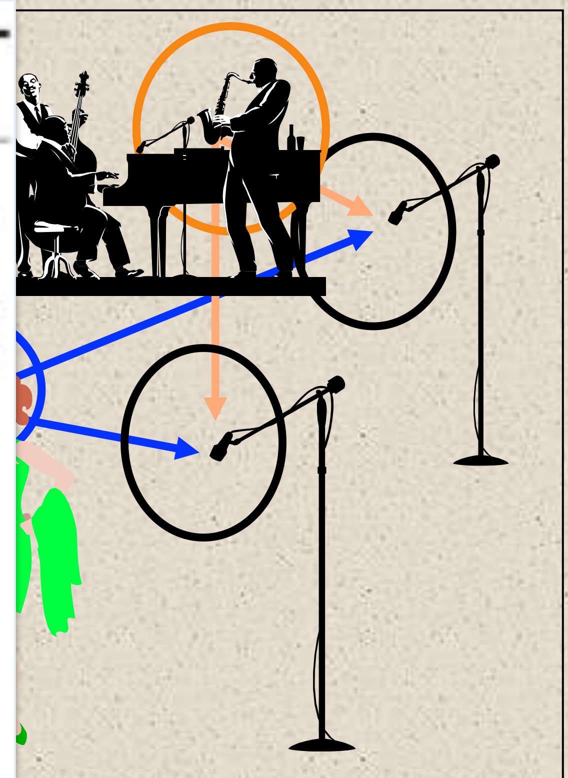
Scott Makeig

Anthony J. Bell

Tzyy-Ping Jung

Terrence J. Sejnowski

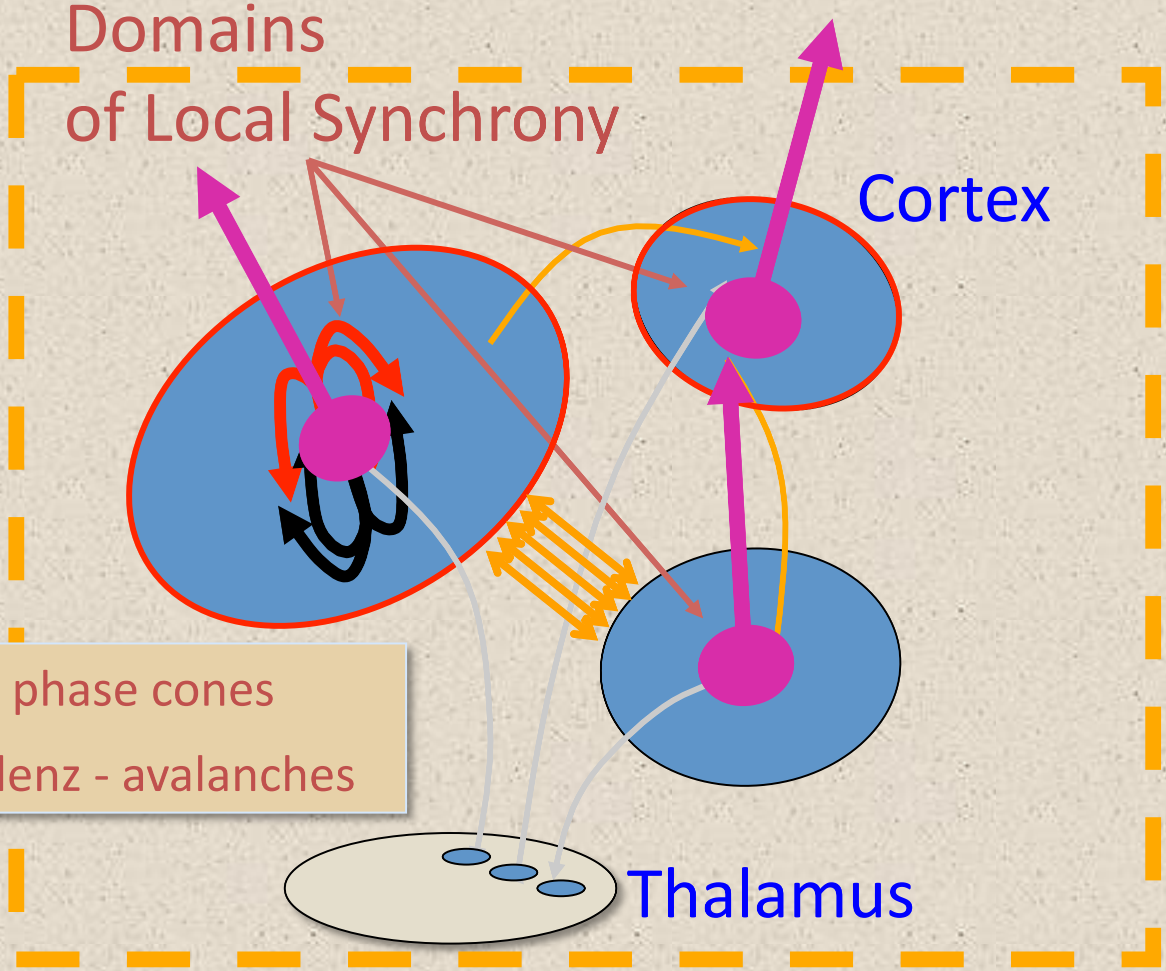
Abstract



Paper: S. Makeig, et al., NIPS (1996)

Are EEG source outputs (near) independent?

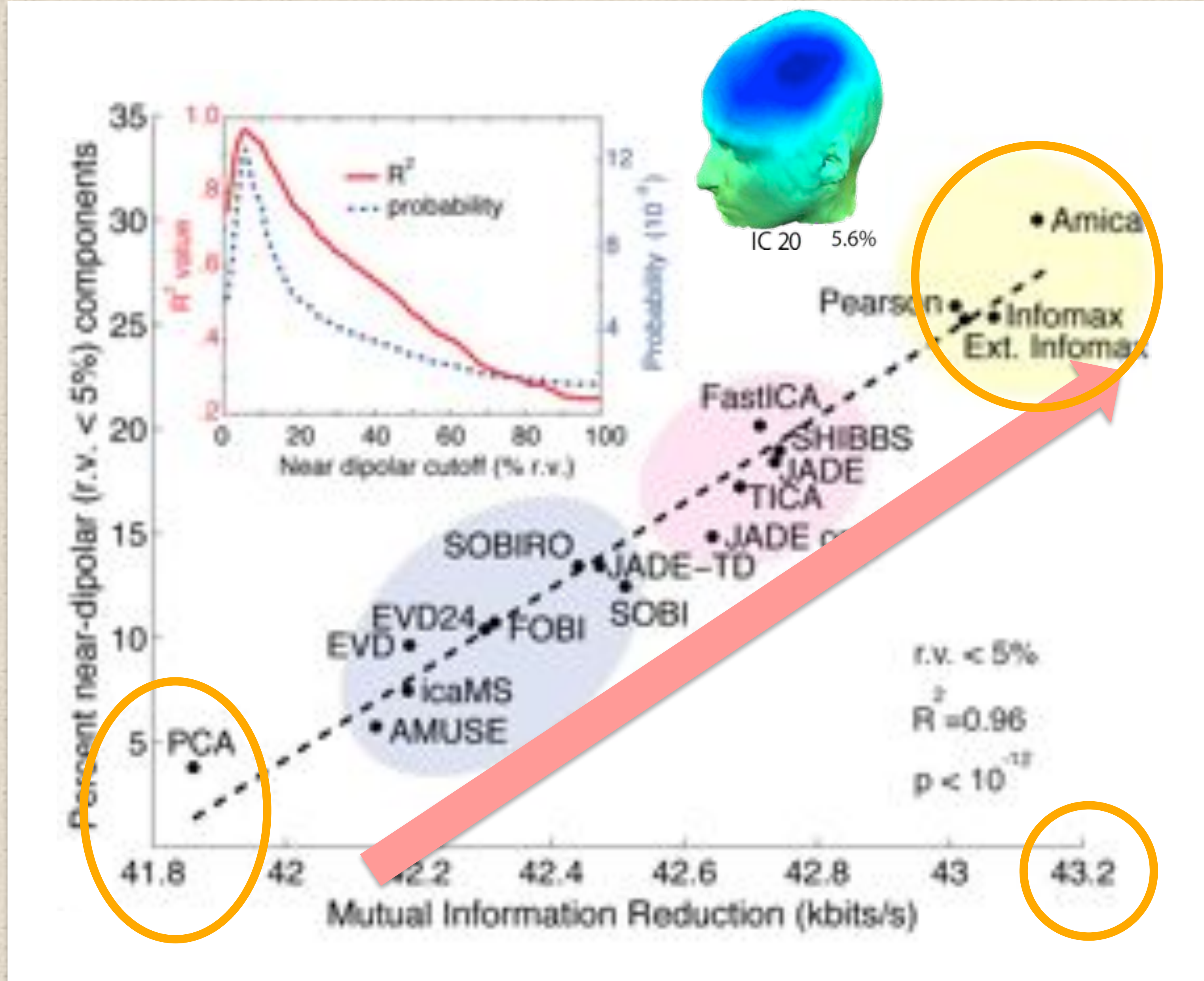
Independent
Domains
of Local Synchrony



Freeman - phase cones

Beggs & Plenz - avalanches

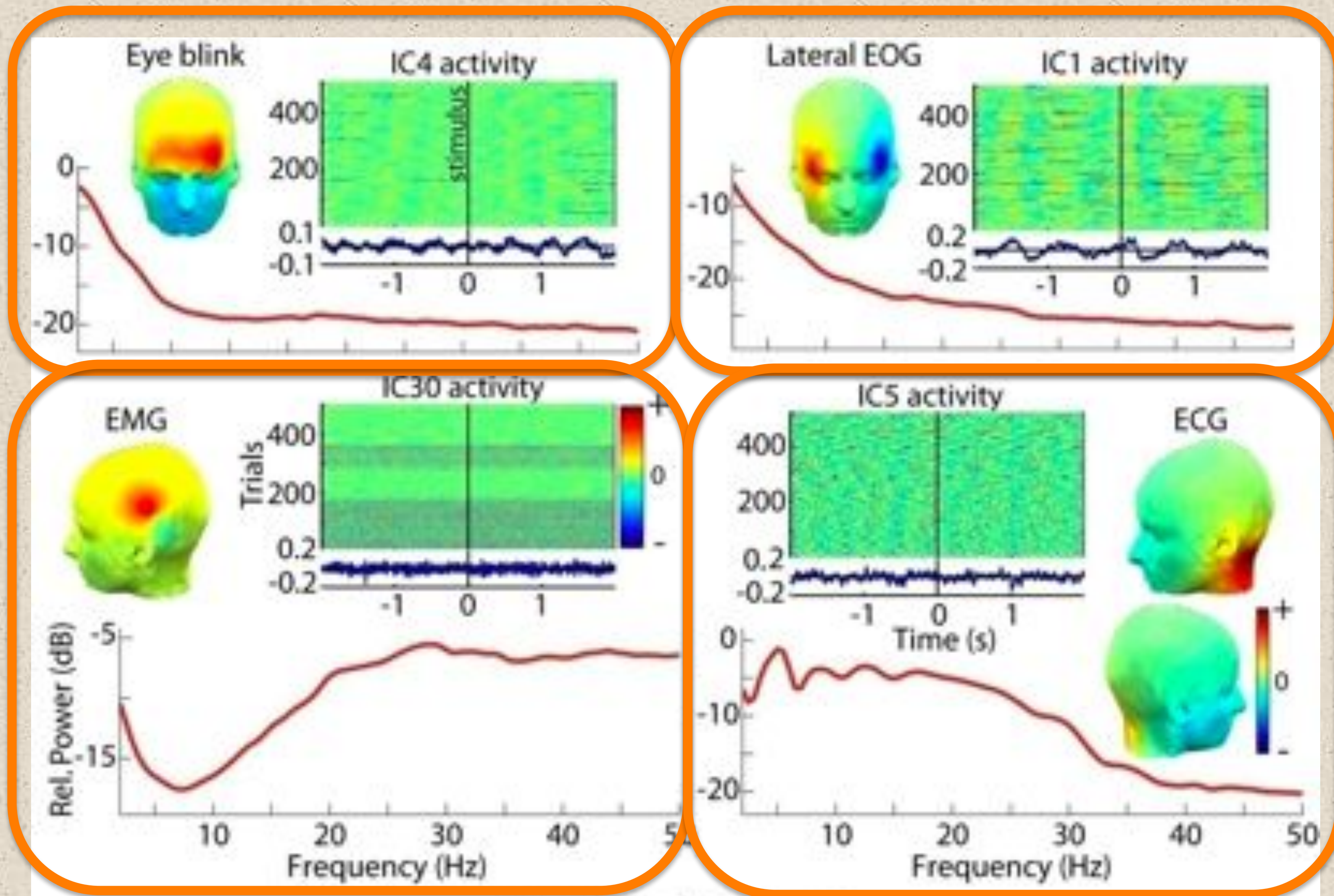
S. Makeig (2007)



Independent EEG Components are Dipolar

Delorme, Palmer, Onton, & Makeig, 2012

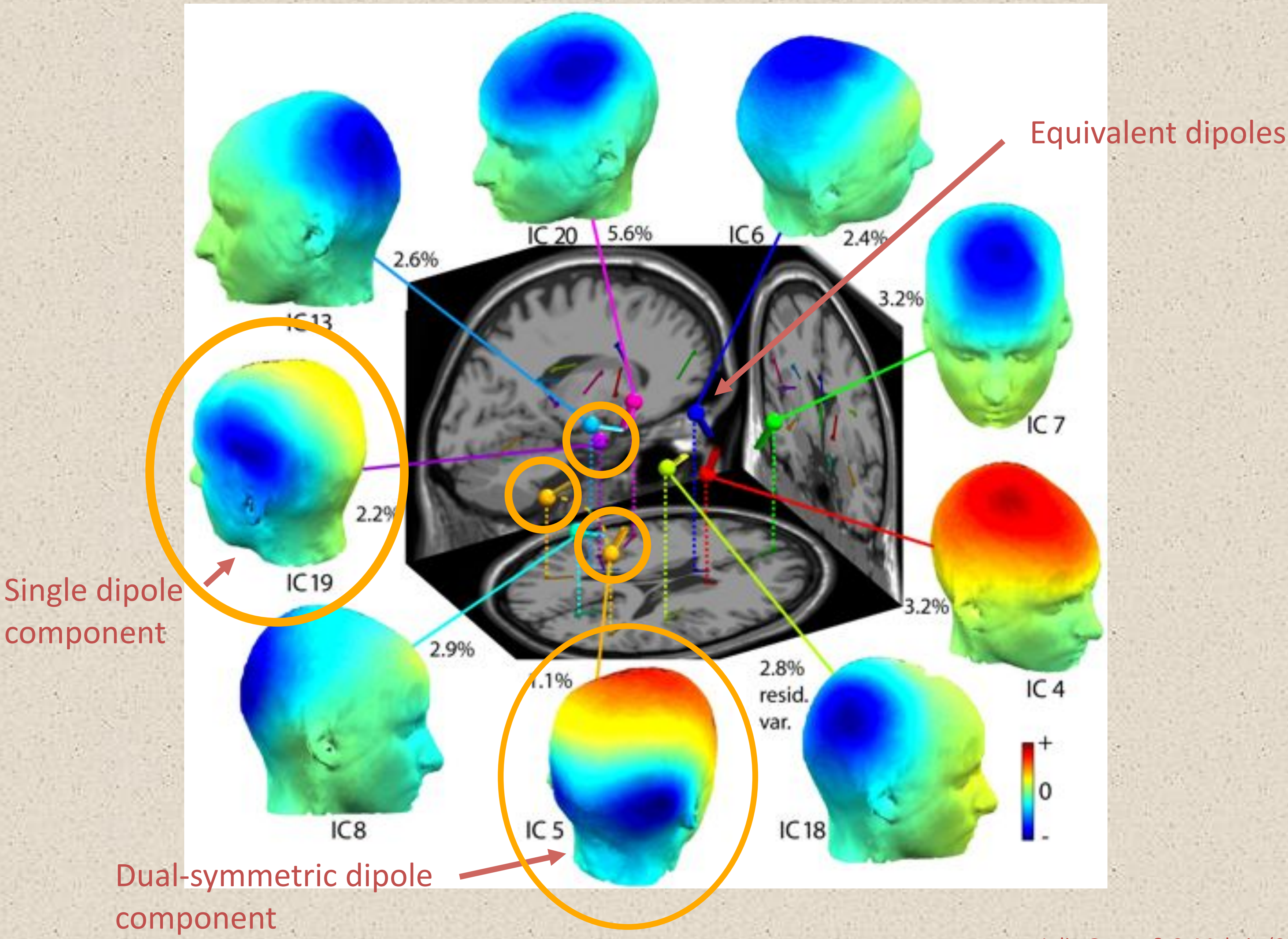
ICA finds Non-Brain Independent Component (IC) Processes …



… separates them from the remainder of the data …

J. Onton & S. Makeig 2006

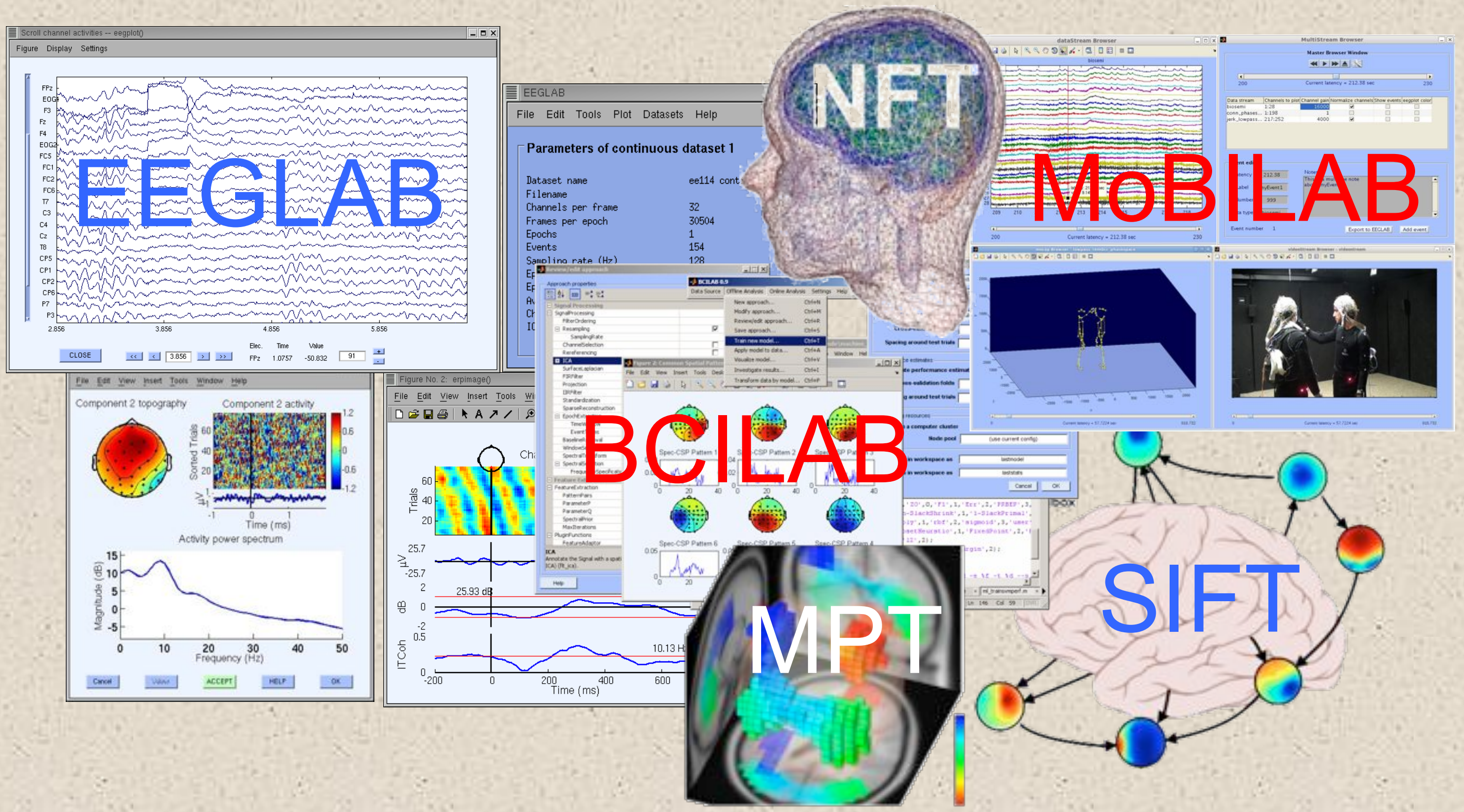
ICA also separates cortical brain IC processes



Julie Onton & S. Makeig (2006)

Swartz Center for Computational Neuroscience

SCCN Open Source Software Tools for MATLAB



Tools available -- but a two-cultures problem ...

S Makeig, 2012

Localizing independent component sources

Scalp EEG source

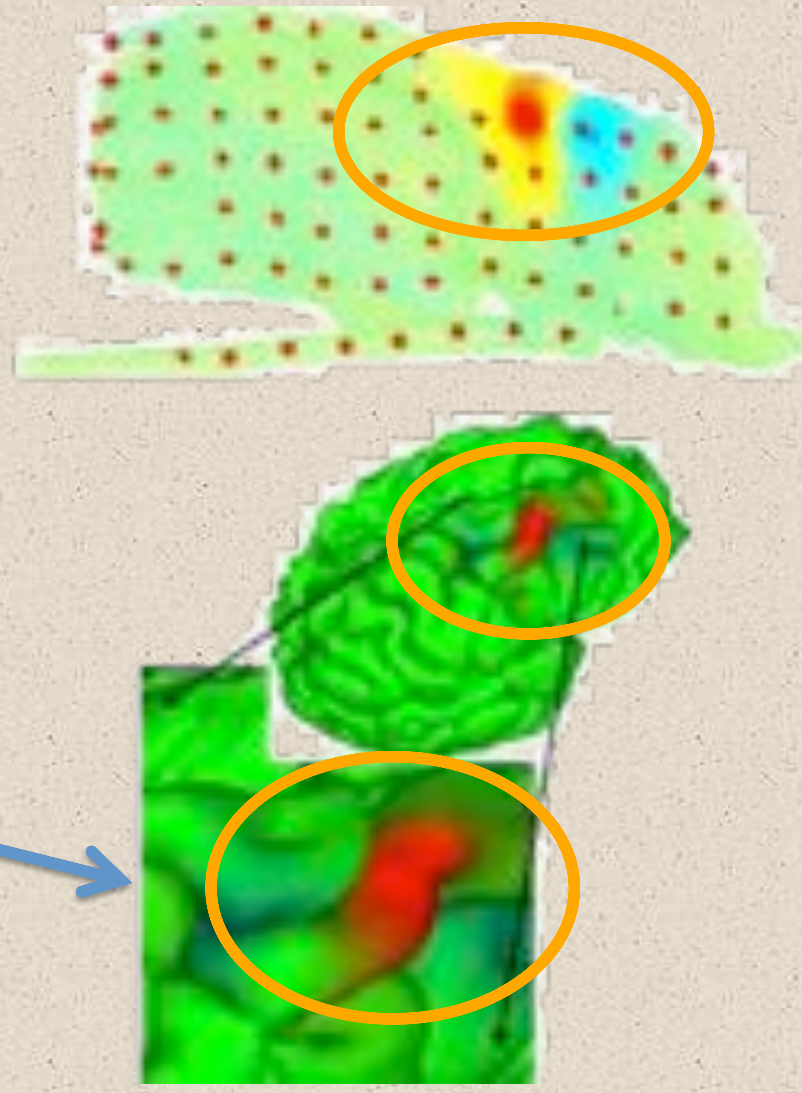
FEASIBLE FOR SCALP EEG ICs?

Will need at least:

- Anatomic MR image
- Accurate electrode positions
- Accurate co-registration
- **Good skull conductivity estimate**

IC source domain estimate

iEEG sulcal seizure source



Z. Akalin Acar, S. Makeig, 2011

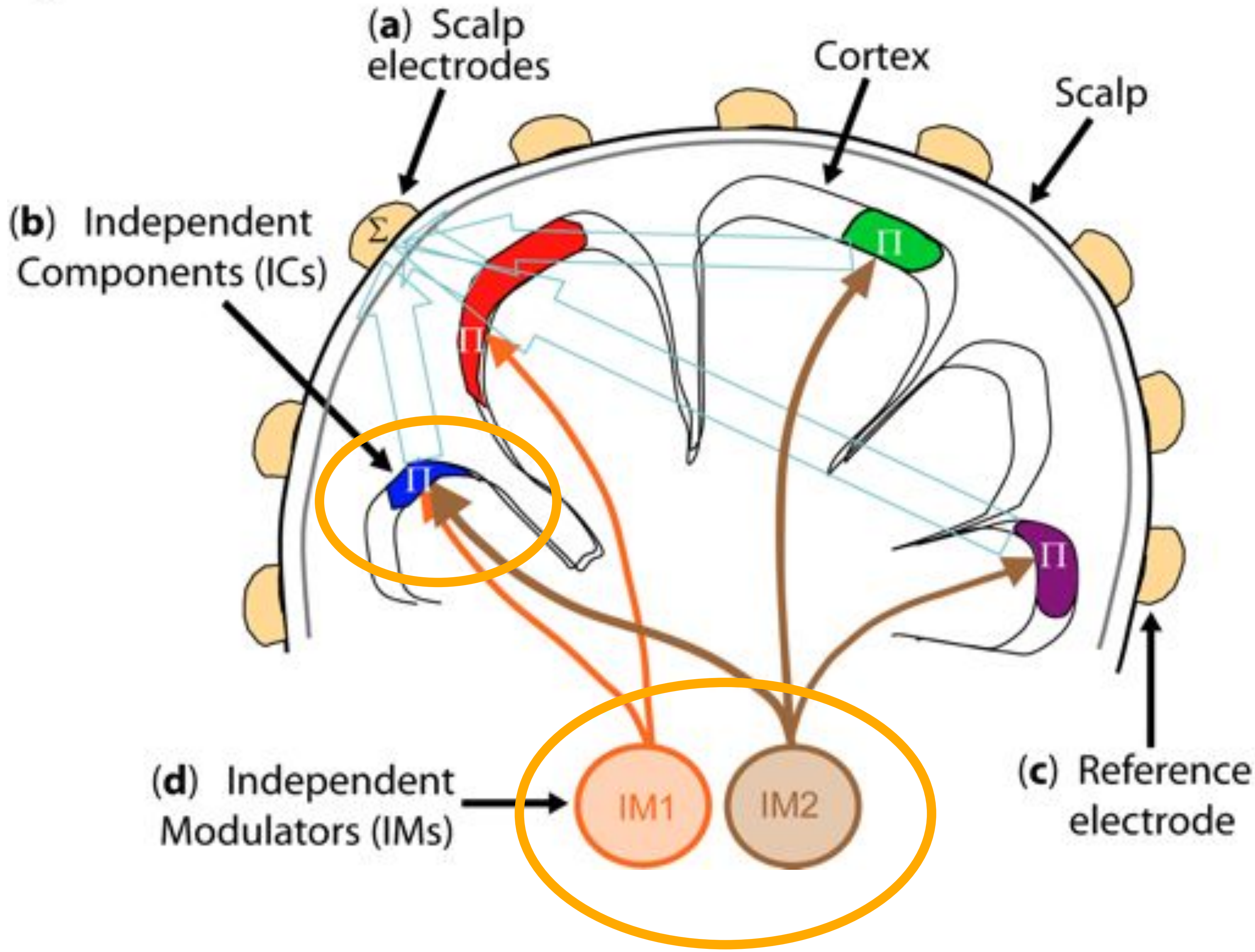
EEG Dynamics of Emotion Imagination

Suggest the imaginative experience of 15 emotions:

- after Helen Bonny (GIM)
- 1sr relaxation induction
- alternate pos and neg emotions
- relax between emotion episodes
- 1-5 min periods of eyes-closed spontaneous EEG x 15 emotions
- 33 subjects

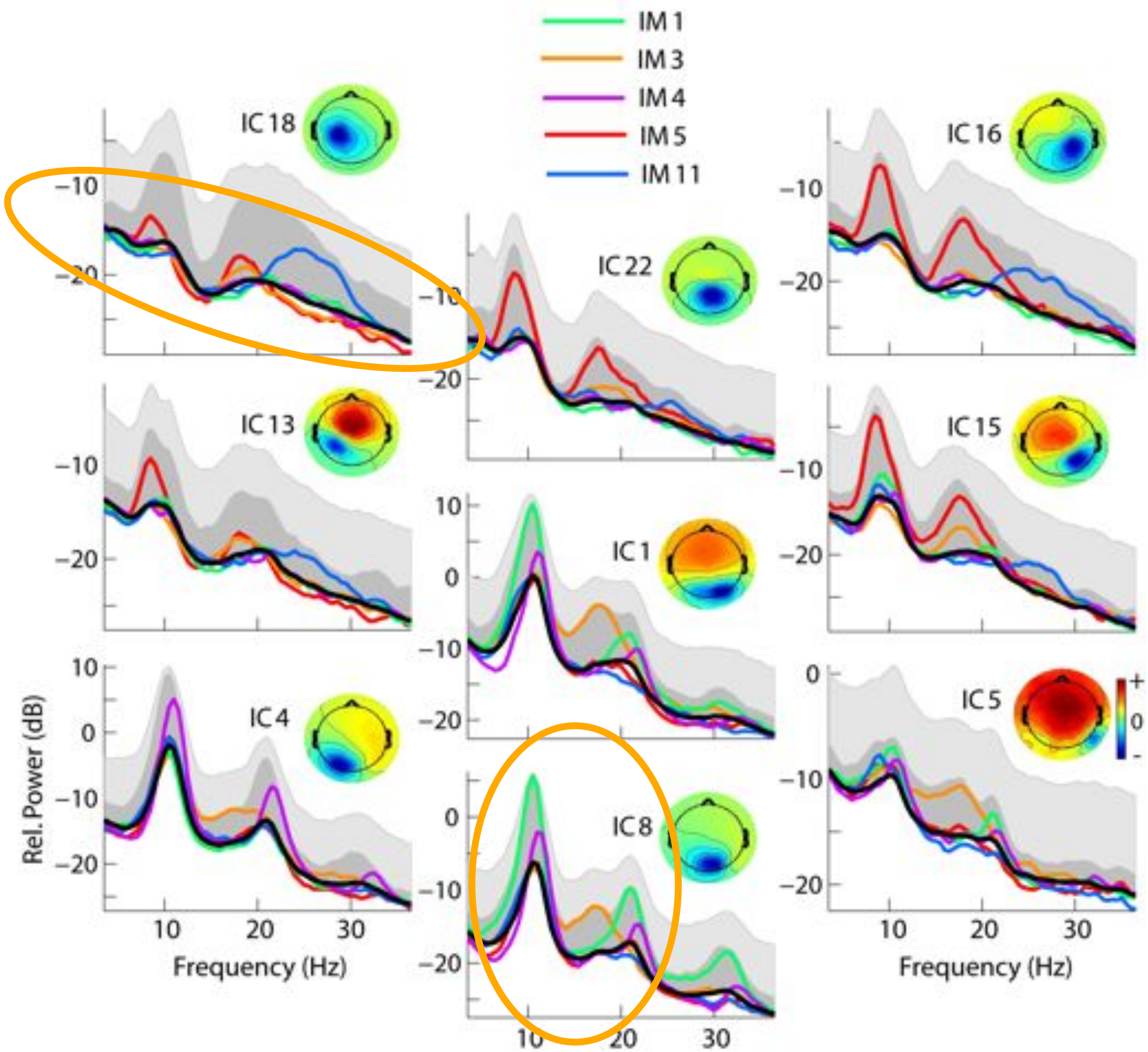
Onton & Makeig, *Frontiers in Human Neuroscience* '09

Independent Modulators



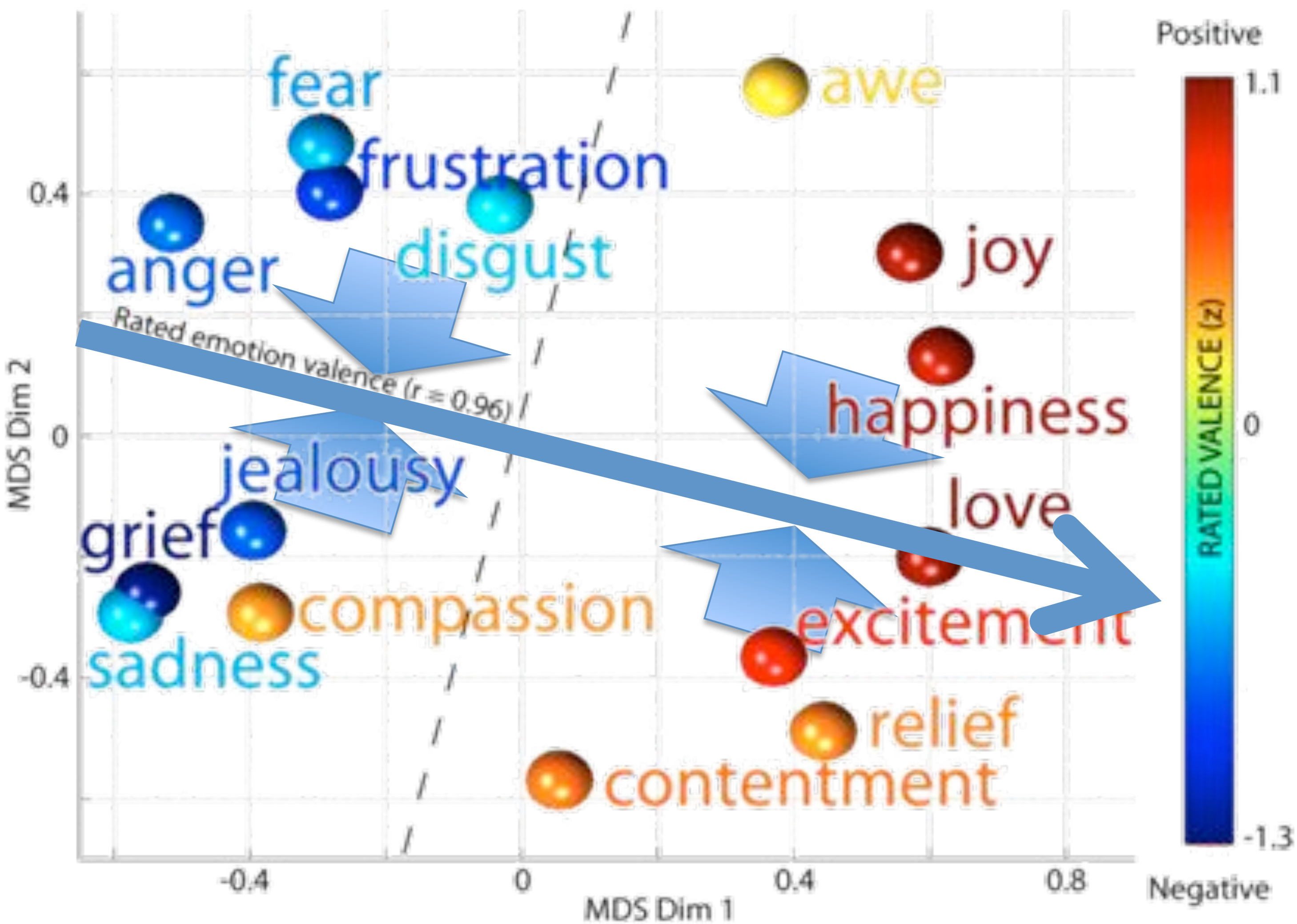
Onton & Makeig, *Frontiers in Human Neuroscience* '09

Independent modes of spectral modulation



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

Changes in distribution of **broadband high-frequency** EEG power with imagined emotions



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

ICA for BCI ?

IEEE TRANSACTIONS ON REHABILITATION ENGINEERING, VOL. 8, NO. 2, JUNE 2000

A Natural Basis for Efficient Brain-Actuated Control

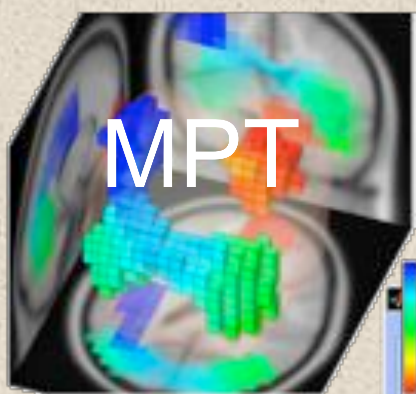
Scott Makeig, Sigurd Enghoff, Tzyy-Ping Jung, and
Terrence J. Sejnowski

***Abstract*—The prospect of noninvasive brain-actuated control of computerized screen displays or locomotive devices is of interest to many and of crucial importance to a few 'locked-in' subjects who experience near total motor paralysis while retaining sensory and mental faculties. Currently several groups are attempting to achieve brain-actuated control of screen displays using operant conditioning of particular features of the spontaneous scalp electroencephalogram (EEG) including central μ-rhythms (9–12 Hz). A new EEG decomposition technique, independent component analysis (ICA), appears to be a foundation for new research in the design of systems for detection and operant control of endogenous EEG rhythms to achieve flexible EEG-based communication. ICA separates multichannel EEG data into spatially static and temporally independent components including separate components accounting for posterior alpha rhythms and central μ activities. We demonstrate using data from a visual selective attention task that ICA-derived μ-components can show much stronger spectral reactivity to motor events than activity measures for single scalp channels. ICA decompositions of spontaneous EEG would thus appear to form a natural basis for operant conditioning to achieve efficient and multidimensional brain-actuated control in motor-limited and locked-in subjects.**

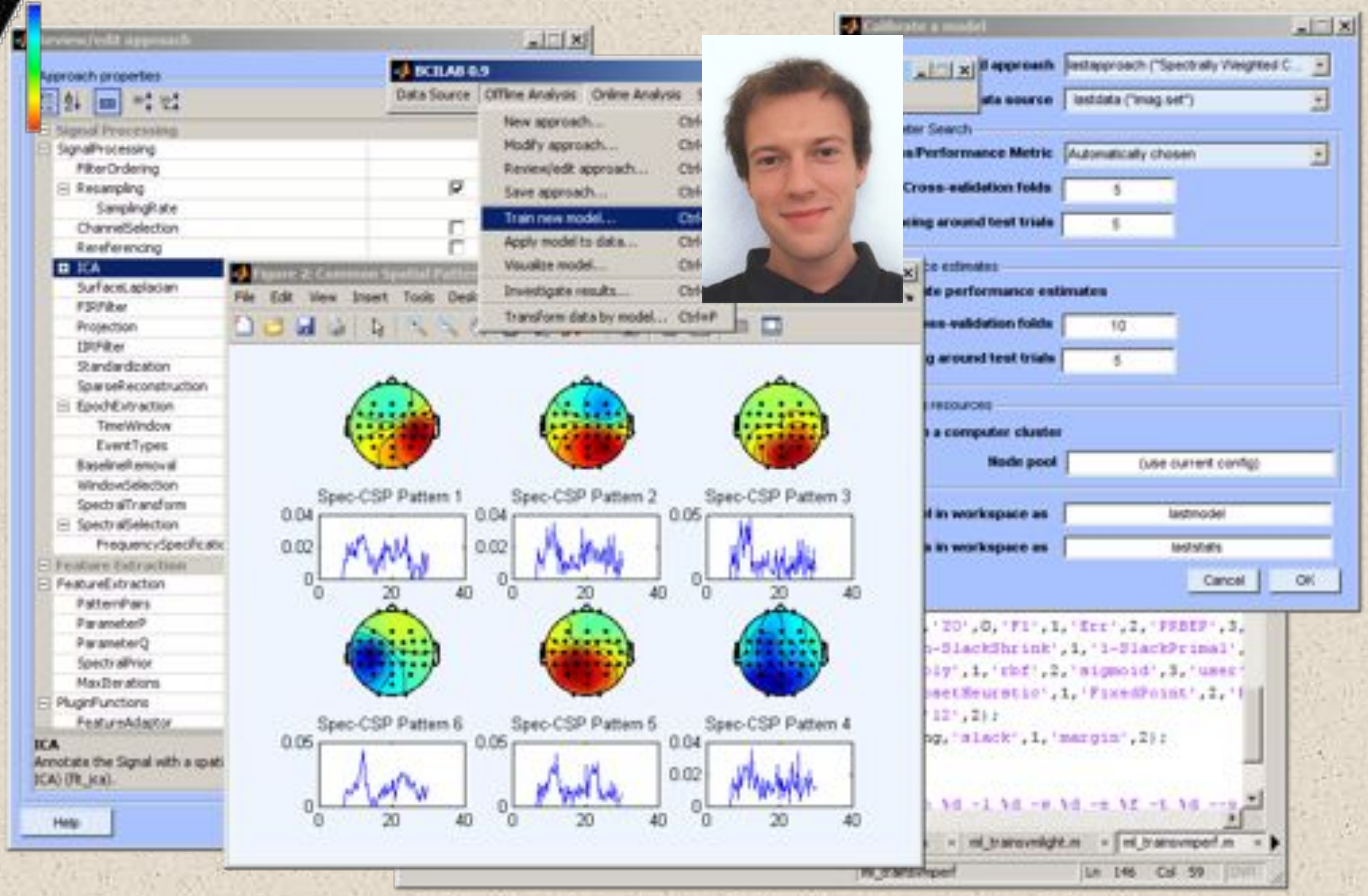
I. Introduction

Recent work in several laboratories has demonstrated that noninvasively recorded electric brain activity can be used to voluntarily control switches and communication channels, allowing a few so-called locked-in near-totally paralyzed subjects the ability to communicate, however slowly, with their families and aides ([4]; [14]; [2]). Communication rates achieved to date are in the range of several bits a

Makeig et al., *IEEE Trans Rehab. Engin.*, 2000



BCILAB

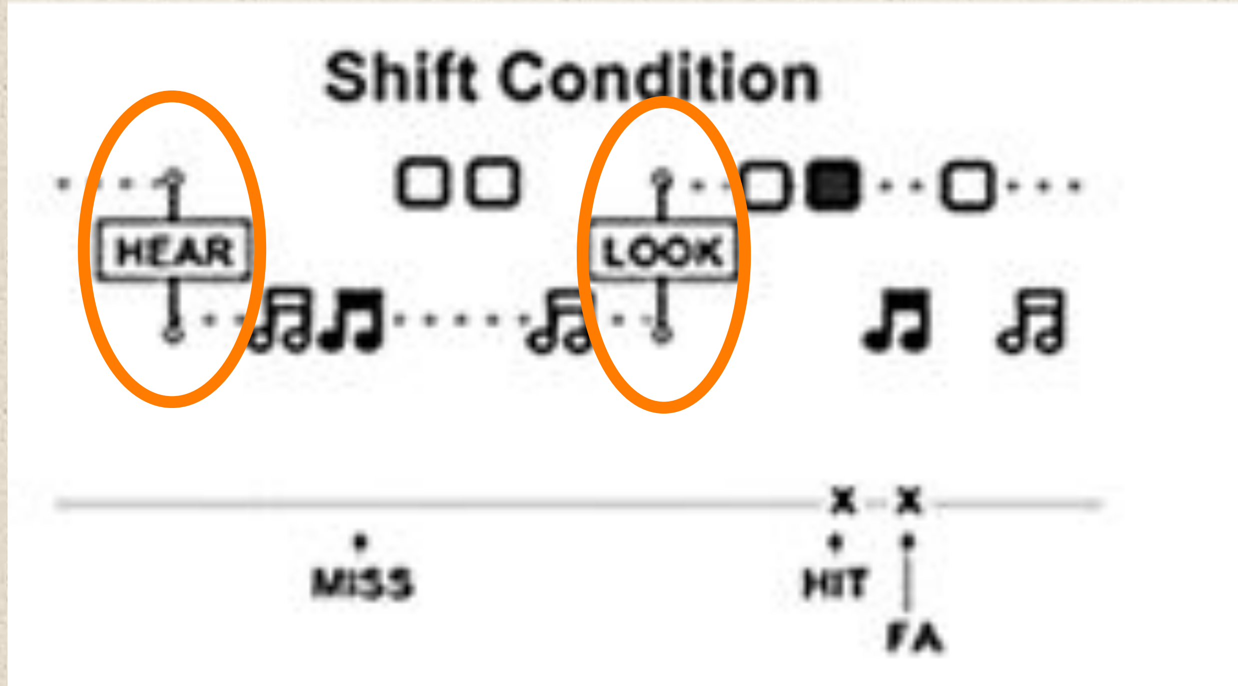


sccn.ucsd.edu/**wiki**/**BCILAB**

C Kothe & N Bigdely-Shamlo 2011

Audiovisual Attention Shift Experiment

Question: What is the brain activity signature of switching between auditory and visual attention?

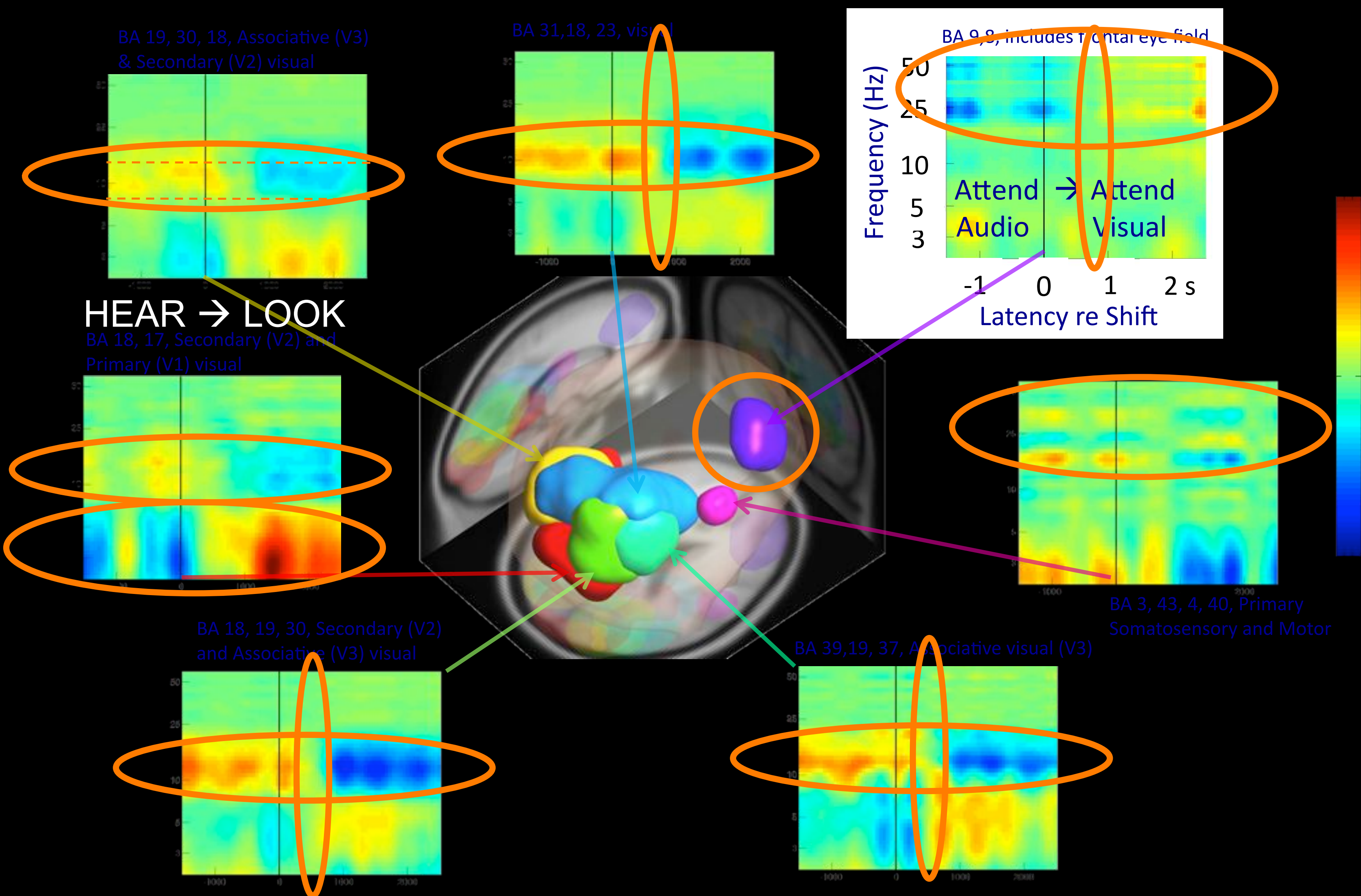


Challenge: Given EEG epochs each time-locked to a HEAR or LOOK cue, train a model to estimate, from the EEG in each epoch, in which direction attention switched (HEAR→LOOK or LOOK→HEAR).

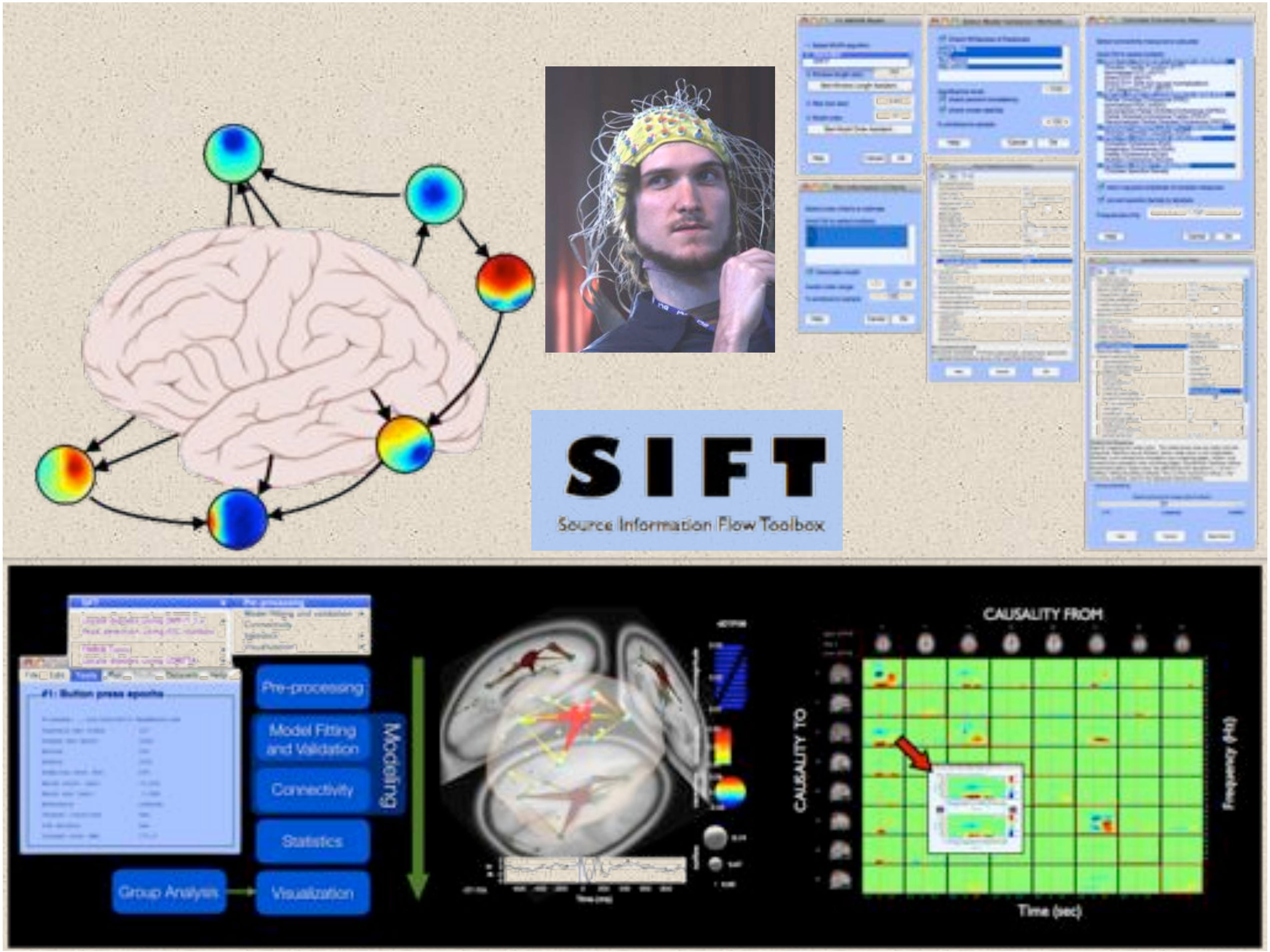
Data: J Townsend et al., 2003

An EEG Attention-Shift Network

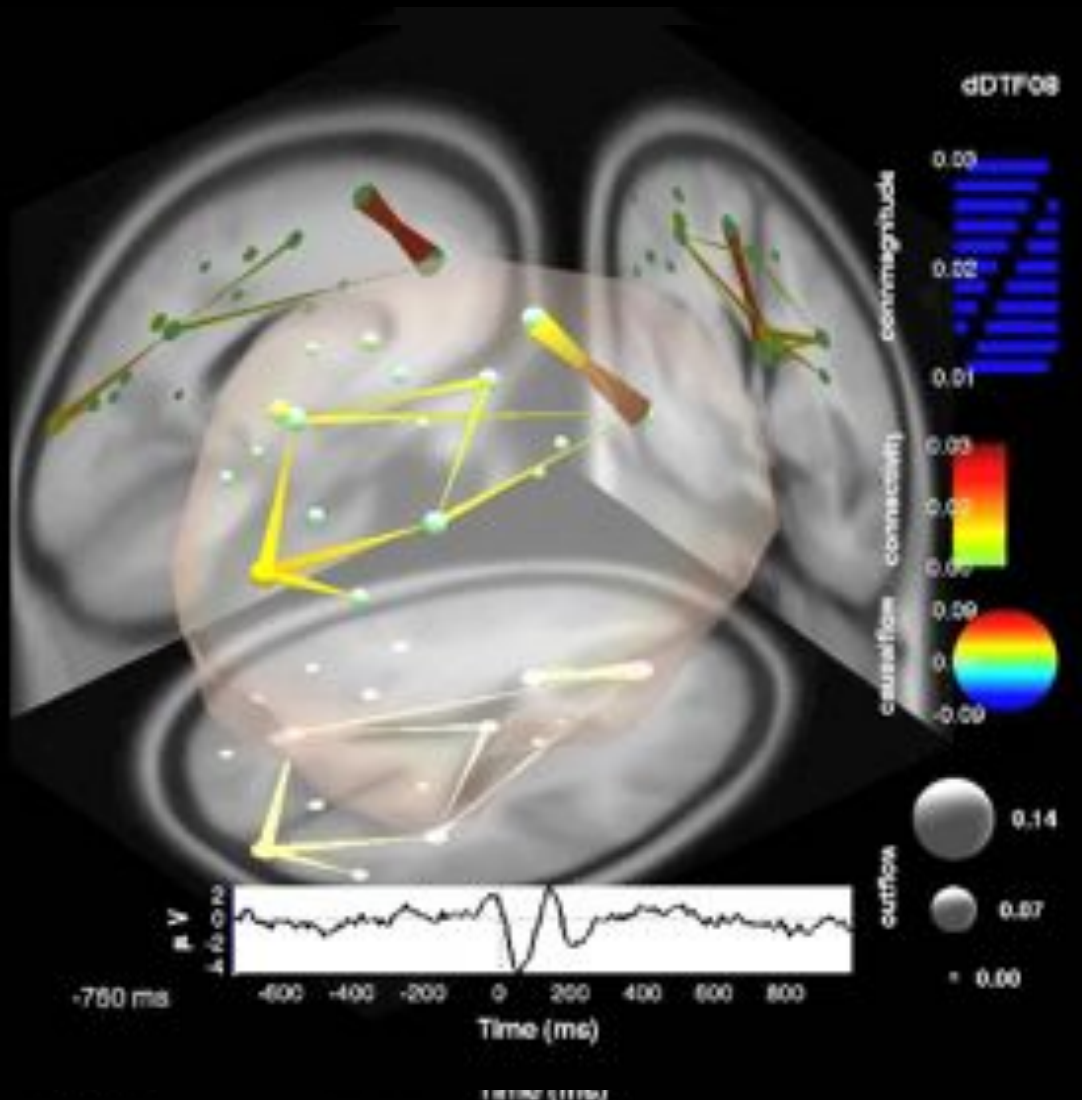
Informative Feature Analysis



C Kothe, N Bigdely-Shamlo, S Makeig , in preparation 2011


SIFT
Source Information Flow Toolbox
#1: Button press epochs
Pre-processing
Model Fitting and Validation
Connectivity
Statistics
Modeling
Group Analysis
Visualization
CAUSALITY FROM
CAUSALITY TO
Frequency (Hz)
Time (sec)

Transient ERN Theta Network Connectivity



Tim Mullen, S. Makeig et al. unpublished

MoBI

Mobile Brain/Body Imaging

Record what the brain does,
What the brain experiences,
And what the brain organizes.

S. Makeig 2007

Brain imaging during motor behavior?

- Nearly all brain imaging studies (MEG, PET, fMRI, and EEG) are conducted in rigidly static s… ted or prone positions with only the most minimal fi… movem… allowed.

Why?

- In all modalities but EEG, … ors are **heavy**.
- Muscle and movements contri… (‘noise’) signals.

- **But this limitation is highly artificial.** Nearly all our life … lves *active movements* and *interactions* within a 3-D environment.
- → **Brain activity during free movement in 3-D space**

has never been observed or modeled!

Mobile Brain/Body Imaging (MoBI) Concept

1. Record simultaneously, during naturally motivated behavior,

What the brain does (high-density EEG)

What the brain experiences (sensory scene recording)

What the brain organizes (body & eye movements, psychophysiology)

2. Then –

Use evolving machine learning methods

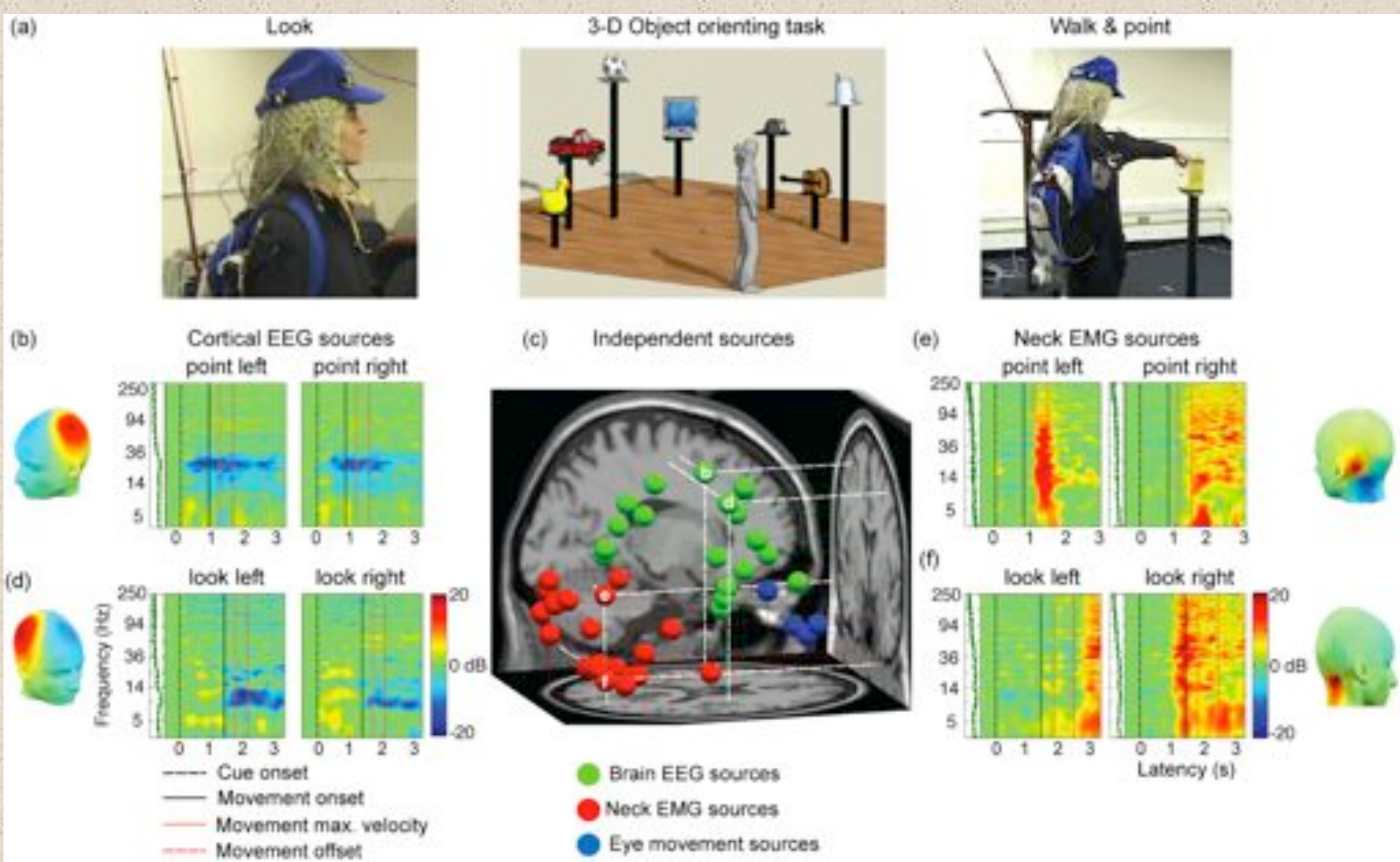
to find, model, and measure

non-stationary (context- and intention-related)

functional relationships among these data modalities.

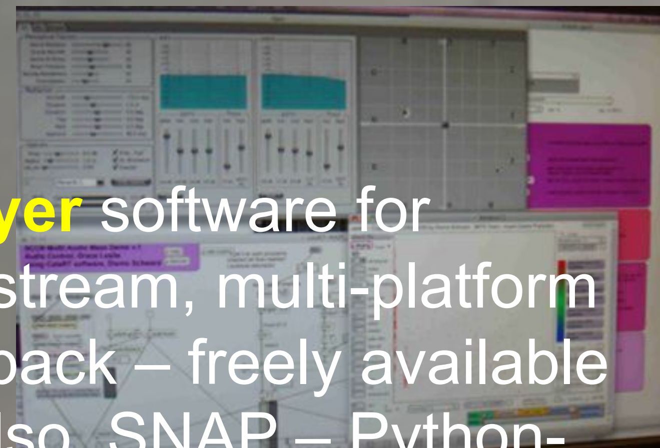
Scott Makeig, 2011

MoBI: Mobile Brain/Body Imaging

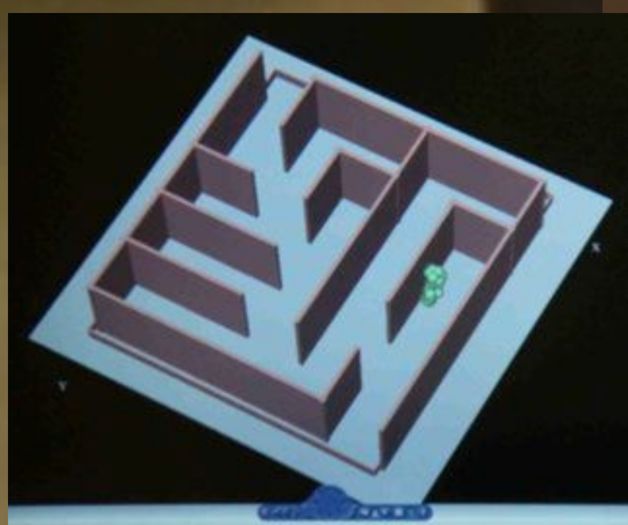


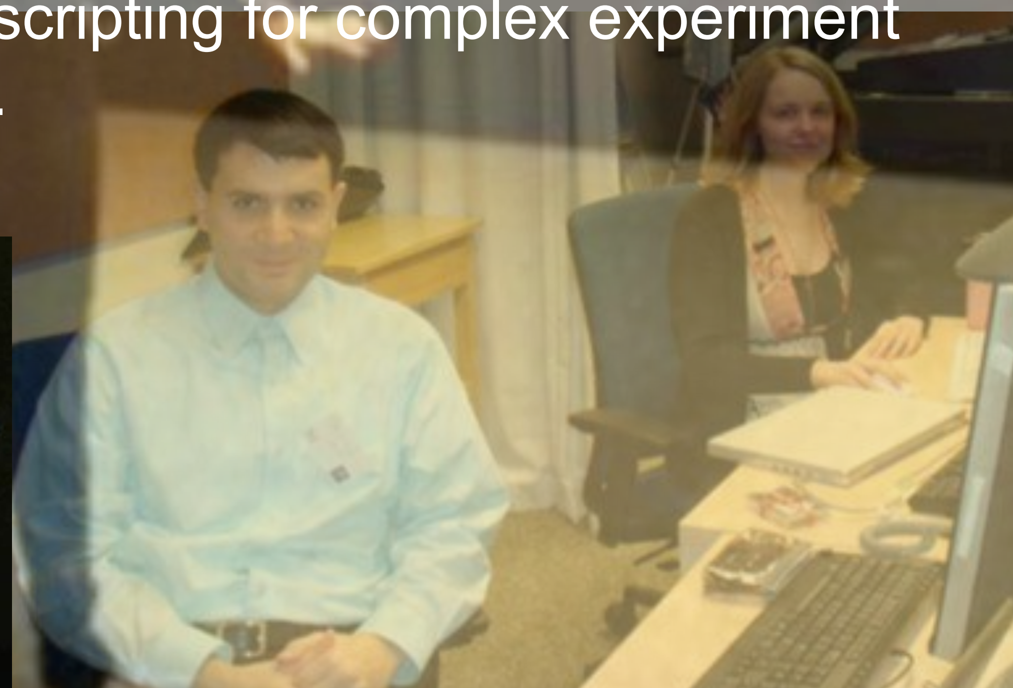
S. Makeig et al., *Int J Psychophysiology* 2009

MoBI Lab at SCCN, UCSD



Lab Streaming Layer software for synchronous multi-stream, multi-platform recording and feedback – freely available on Google Code. Also, SNAP – Python-based scripting for complex experiment control.





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

MoBI experiment in progress: S Makeig & M Miyakoshi, 20112

MoBI Lab: Two-Person Mirroring Experiment

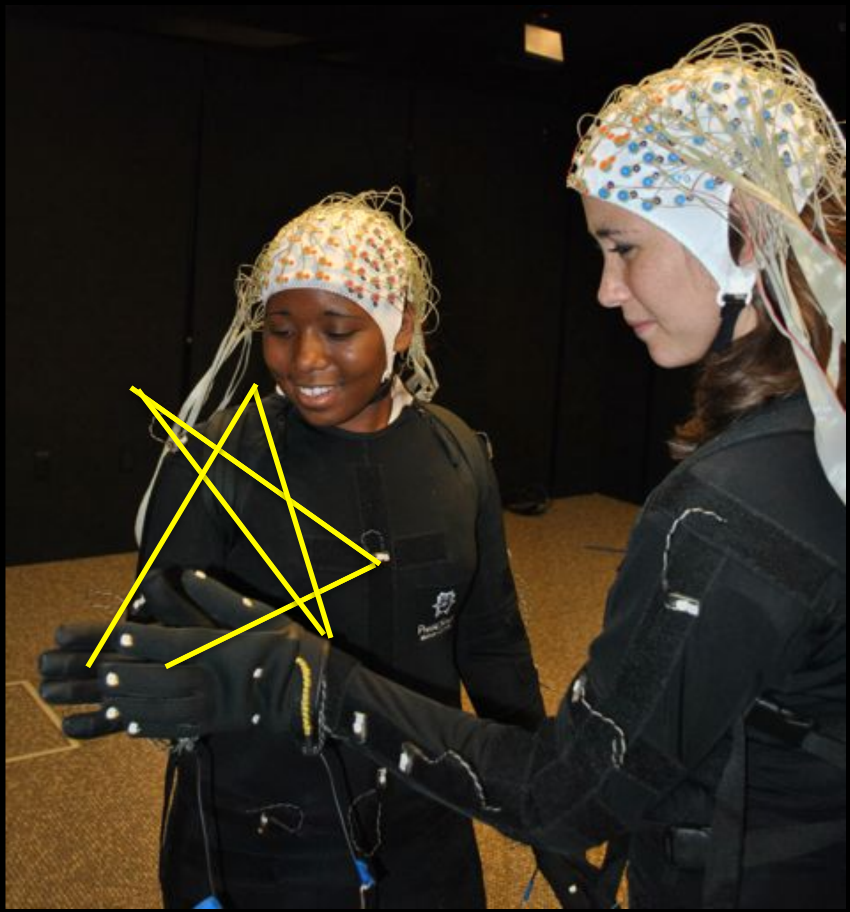
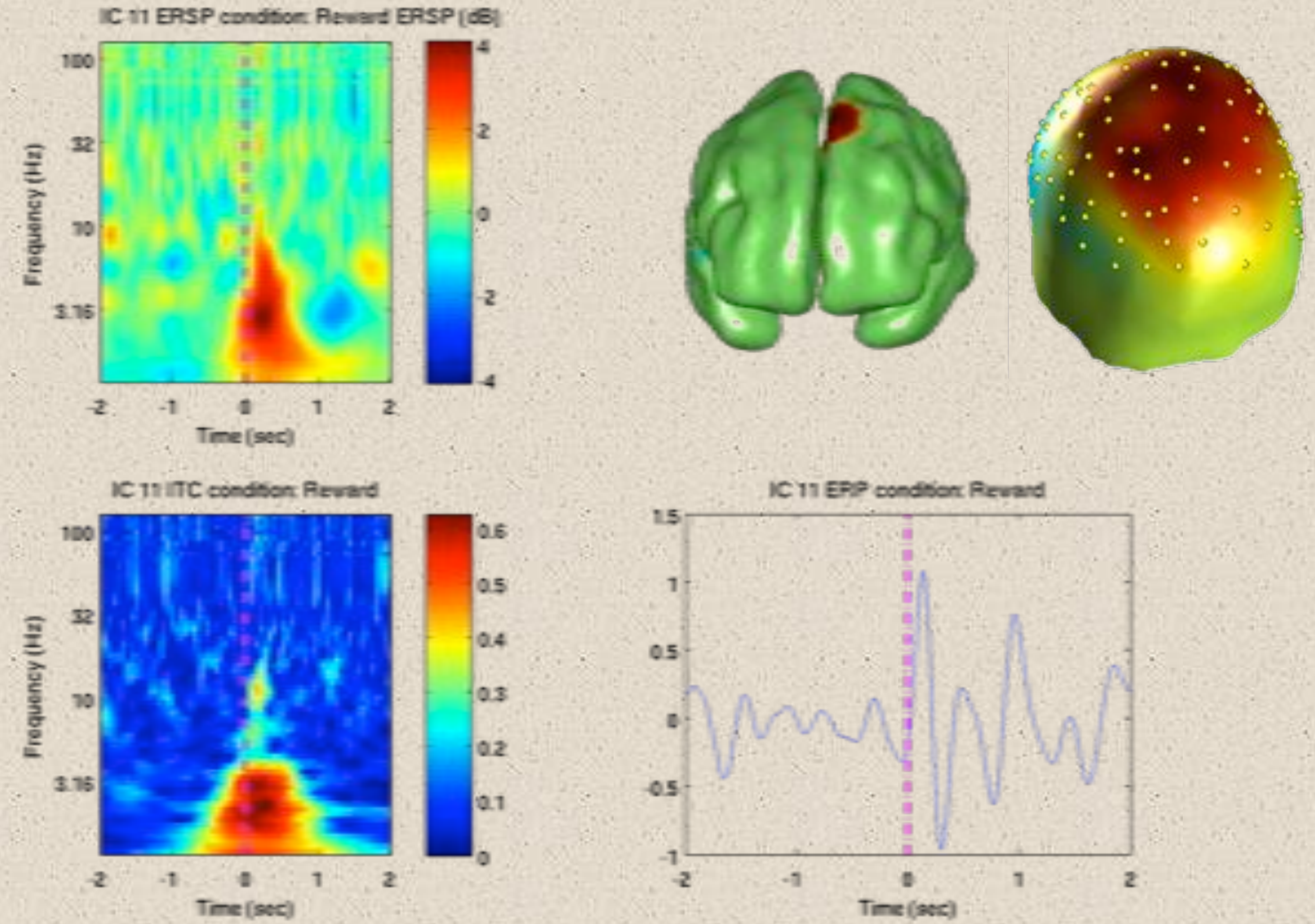


Photo: T Bel Bahar & E Tumer, 2011

MoBI Lab: Two-Person Mirroring Experiment

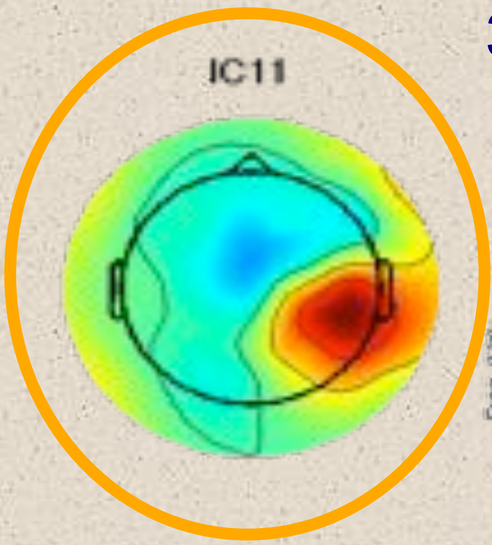


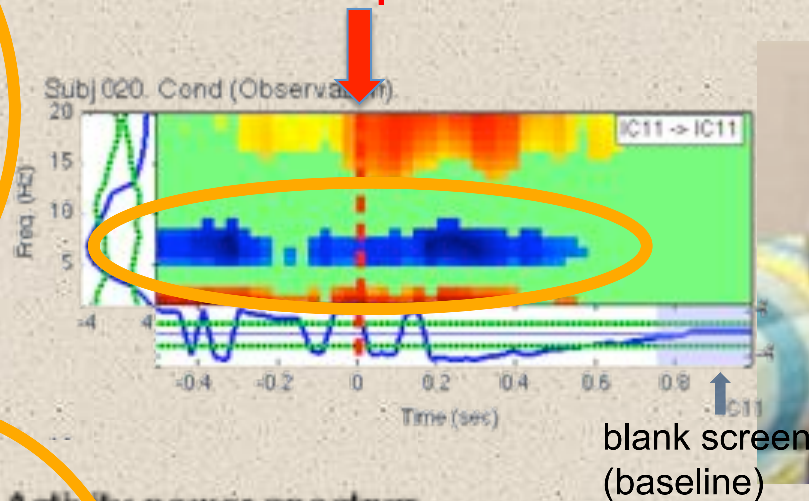
Development of Shared Attention –
A Mother and Child MoBI Experiment

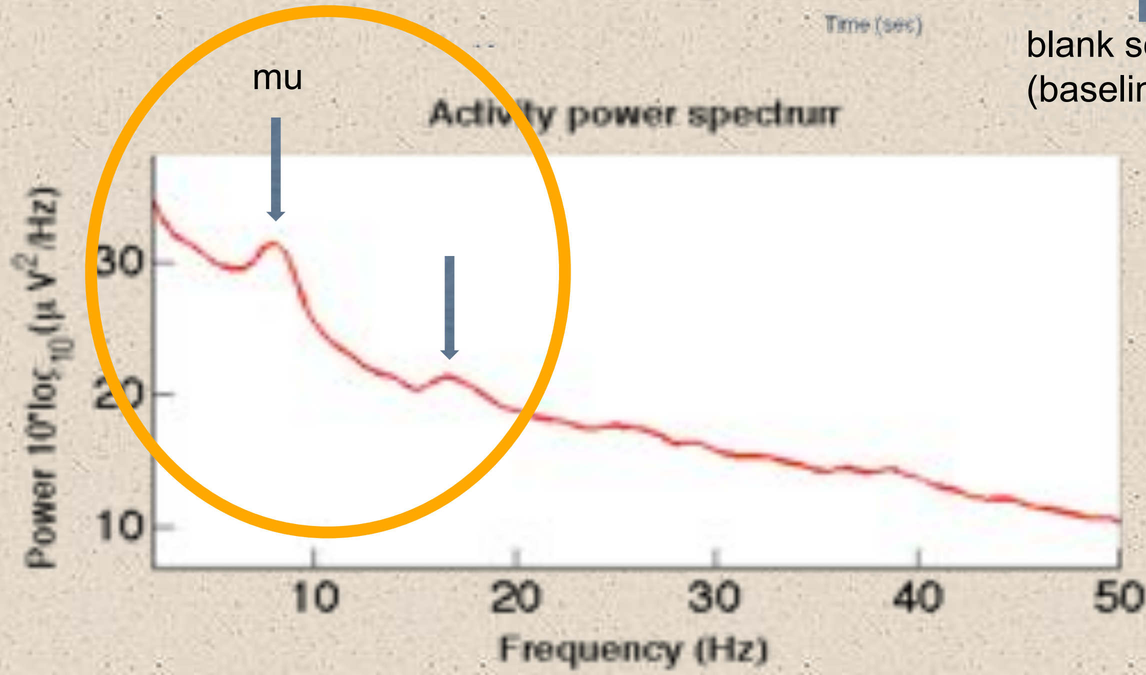
Gedeon Deak et al., 2011

3-yr old child – Reward Observation

Mother Pops the Bubble!







T Mullen, Yu Liao, ,S Makeig, G. Deak 2011

HeadIT

A Human Electrophysiology

Anatomic Data

& Integrated Tools

Resource

S. Makeig, J Grethe, N Bigdely-Shamlo, 2012

Swartz Center for Computational Neuroscience (SCCN)
UCSD, La Jolla CA

SCCN currently has over 50 researchers and students working on electrophysiological brain dynamics via high-density EEG, ECoG, MoBI, and other data – some 26 of us shown here ...

10th Anniversary SCCN Impromptu celebration 1/2/12