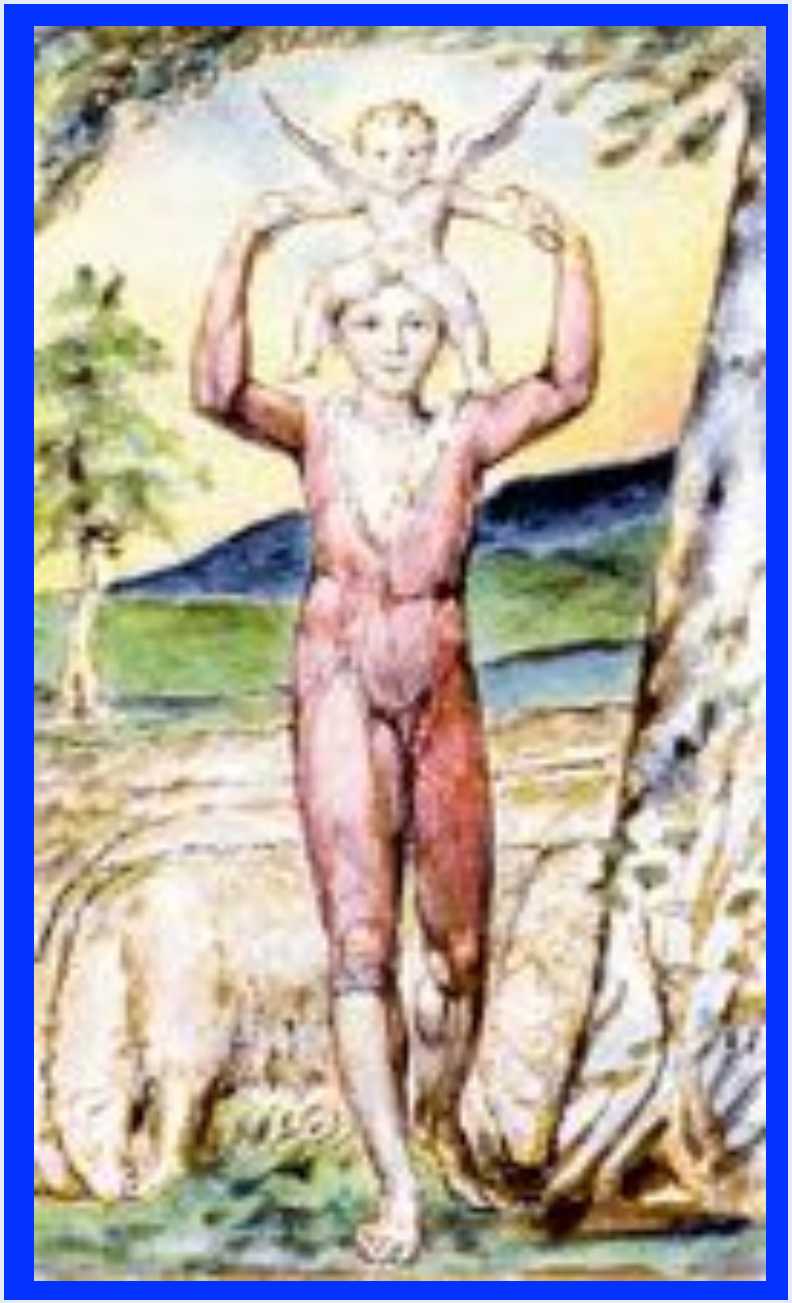


S. Makeig (2013)

Studying the Brain Dynamics of Music, Movement, and Emotion

Scott Makeig
Institute for Neural Computation
University of California San Diego

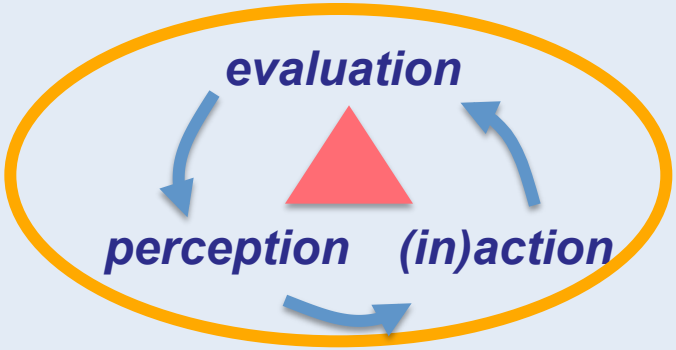
Music & Language Summer School
Tenaya Lodge, Yosemite National Park
May 22, 2014

TOPICS

- How/why do we experience musical affect?
- What is EEG?
- EEG and affect
- EEG and movement
- EEG / music / movement / affect …

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!

S. Makeig 2011

Musicical Affect

Slide: Scott Makeig, 2013

INDIVIDUAL DIFFERENCES IN LISTENING TO MUSIC

By CHARLES S. MYERS. **(1922)**

(From the Cambridge Psychological Laboratory.)

Theory of ~~Mind~~ Heart

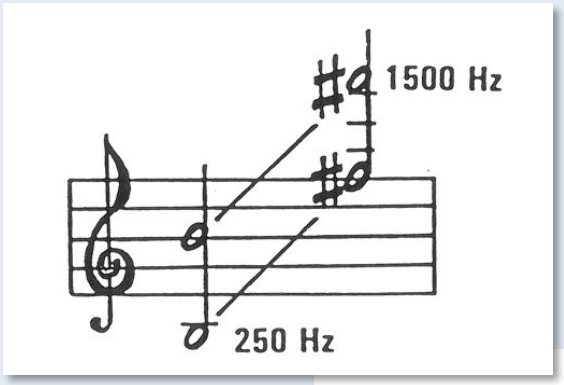
But to discern the feelings of another person (and, thereby, their motivation to act and react), we must typically must use much more subtle cues…

Discernment of human character and affect

https://www.youtube.com/watch?v=sZBKer6PMtM

[1948 animation of squares and triangles interacting –we immediately associate their movements with human emotional interactions]

Two Modes of Octave Perception (1983)



- In tune?
- Sharp or flat?

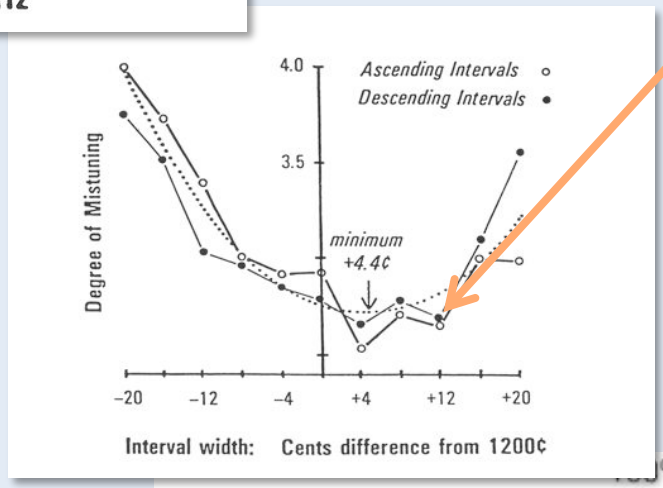


Table 1 - Projective Responses to Ascending Intervals

Cents	Subject DL	Subject JM
1220	second speaker more emphatic, some sort of discord	no real ring, extra energy, questionable intention
1216	second speaker made same statement but worded it better	definite confirmation but mechanical, not really true
1212	both equally convinced both positive	a real confirmation for me, though second speaker added a fair amount of energy, but not overly so
1208	both equally [illegible] second speaker more emphatic	[illegible] ring as true, mechanical, couldn't give the warmth of the first
1204	second speaker just a little bit less assured	second adds energy, verges on over-energetic, but I feel no qualms about it being truly confirming
1200	second speaker a little less assured	really rings clear and true
1196	second speaker not quite as sure	confirming, but wasn't really vibrant, almost routine
1192	second speaker clearly not as confident	doesn't quite confirm, a little routine
1188	second speaker emphasized the negative	doesn't confirm or deny, weak
1184	second speaker negative, discouraged, disgusted	half-hearted
1180	second speaker weakest so far, but with hostility, clearly not so sure	starting to border on countering the first, focused against it

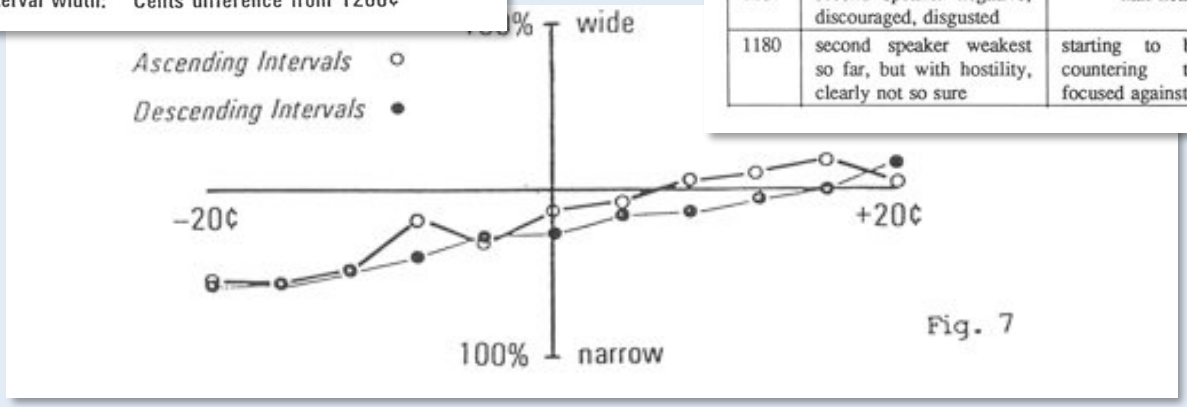
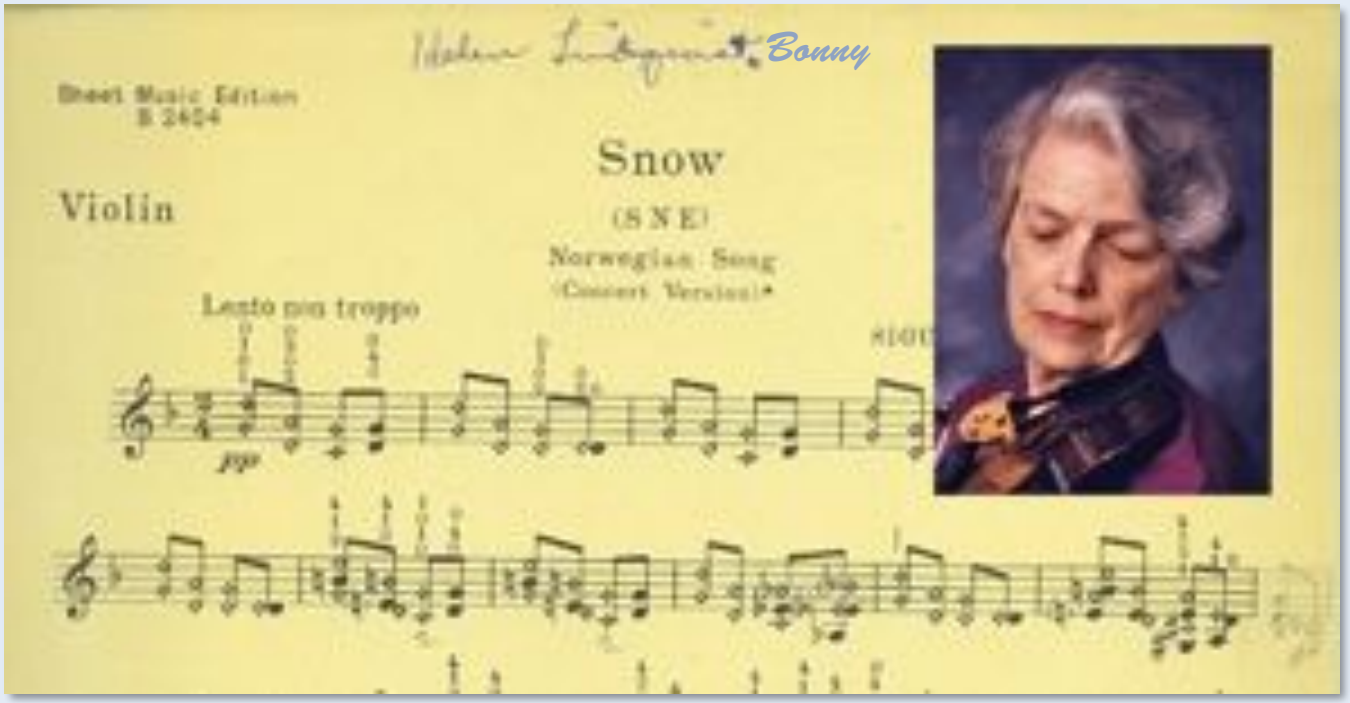


Fig. 7

Guided Imagery Through Music



Music was around me during my childhood years: violin study and practice leading to a degree in violin performance. This led to my opening to depths of emotion, to rhythm, to the spirit within: and then to learn to express these elements to the listener. I got in touch with myself, with music, and with the eternal spaces which music reaches when a great composer opens us to spaceless realities. The culmination came in my early 20's when the music I played took on a surprising new dimension. Upon playing "The Swan" from Saint Saens' Carnival of the Animals, my violin exuded the most beautiful sounds I had ever heard – they were not mine; my bowing and fingers moved as usual but the sounds were ethereal, out of this world. It happened again when I played the "Ave Maria" by Bach-Gounod. The experience had a profound effect upon my life, leading me to a continuing study and practice of spirituality, and eventually, to music therapy where I hoped to further understand the glorious phenomena which had changed my life

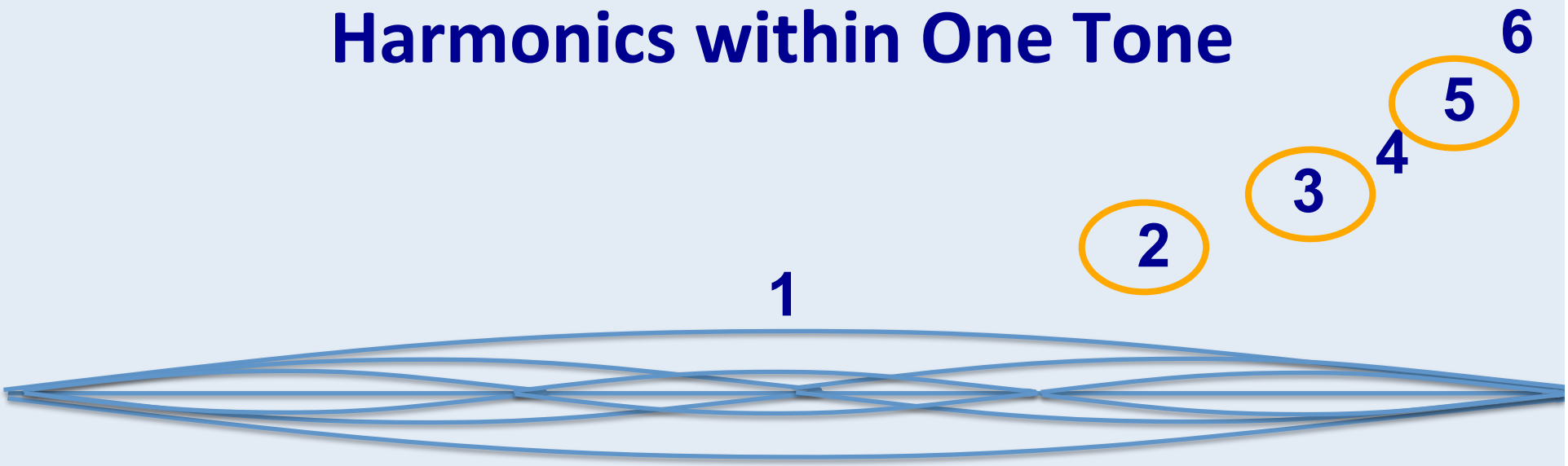
Q: How can I, as a musical composer & performer, communicate *affectively* to listeners?

What elements of music can I employ for this?

- Melody
- Harmony
- Rhythm
- Articulation
- Timbre
- Gesture

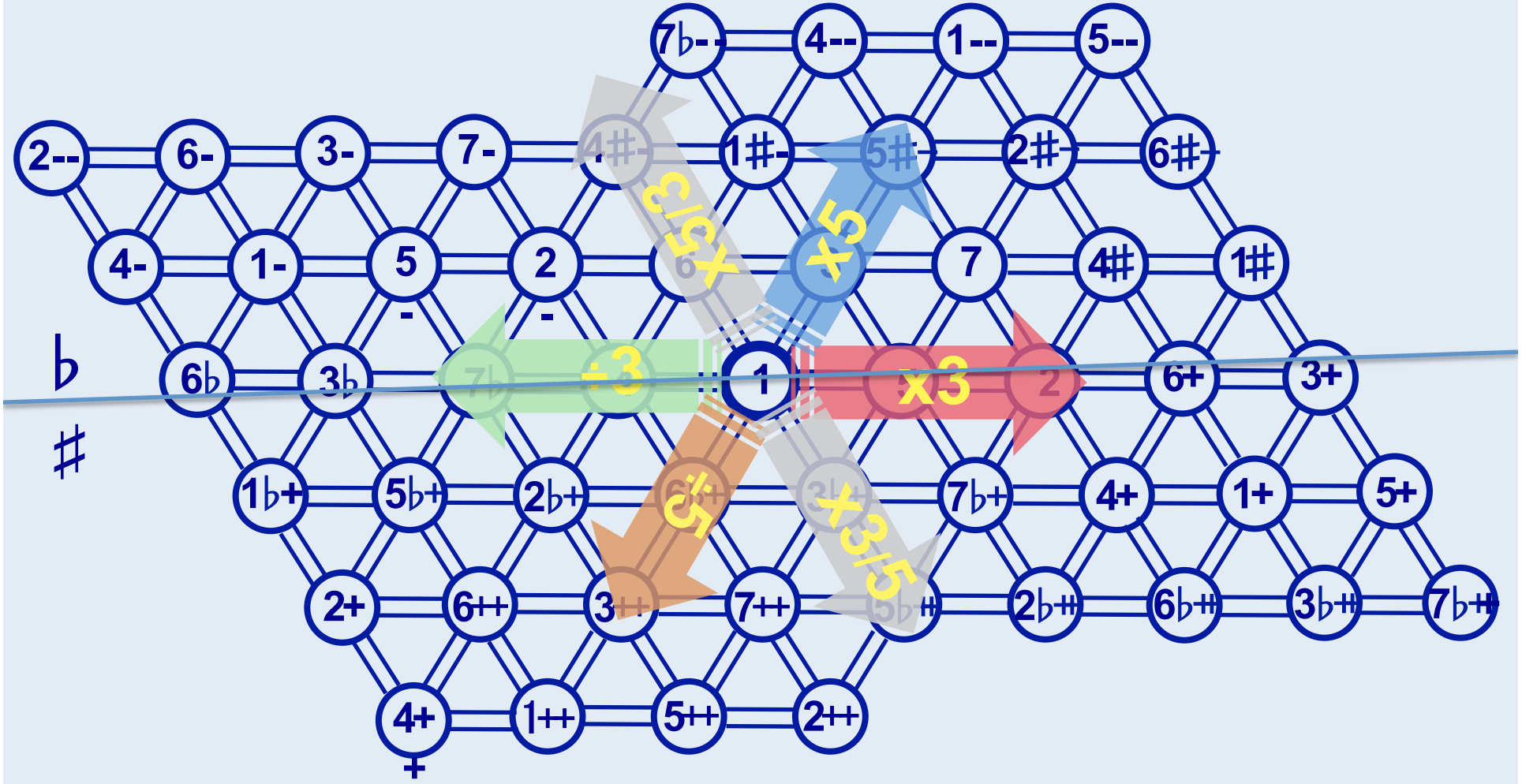
S Makeig, 2013

Harmonics within One Tone

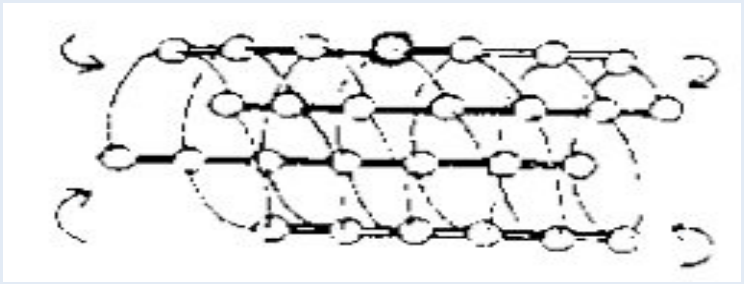


The octave	2/1	= musical equality
The ‘perfect’ fifth	3/1	= 3/2 ratio
The ‘major’ third	5/1	= 5/2 = 5/4 ratio

The Web of Musical Fifths (3/2) and Thirds (5/4)



S Makeig, 2013

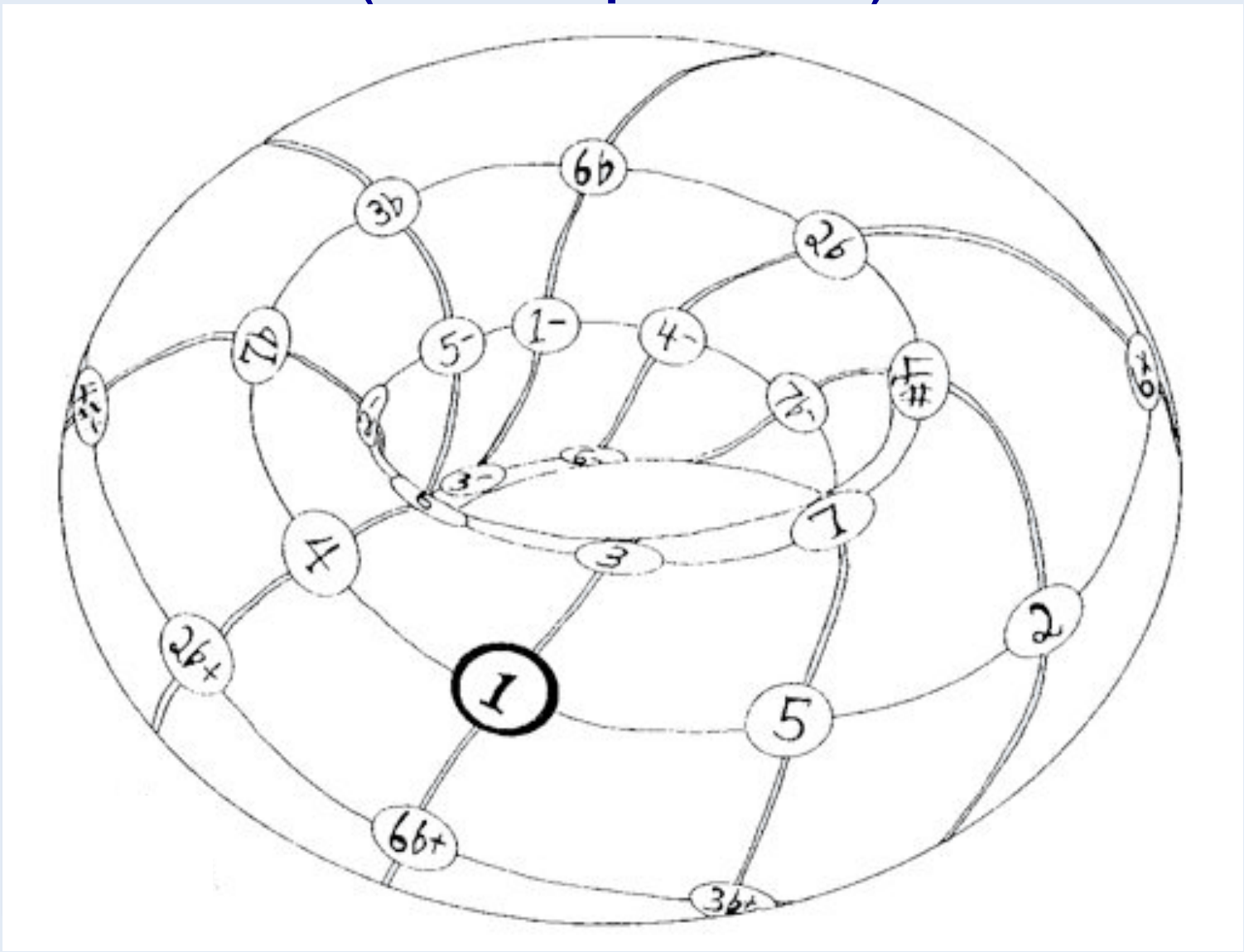


Folding the Enharmonic Tone Group into a 53-note Torus

S Makeig, 2013

The Enharmonic Tone Group

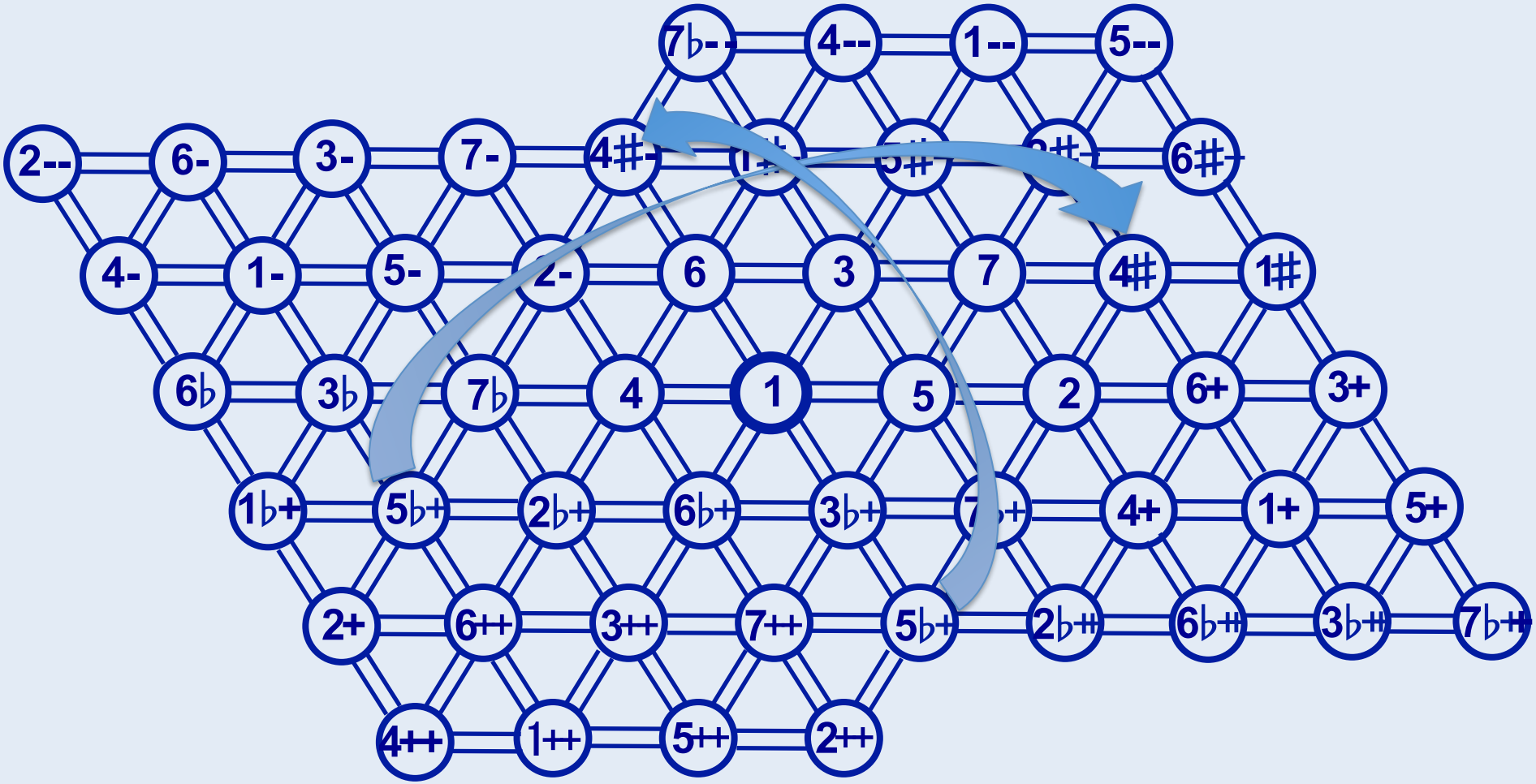
(53 notes per octave)



Web of Fifths and Thirds

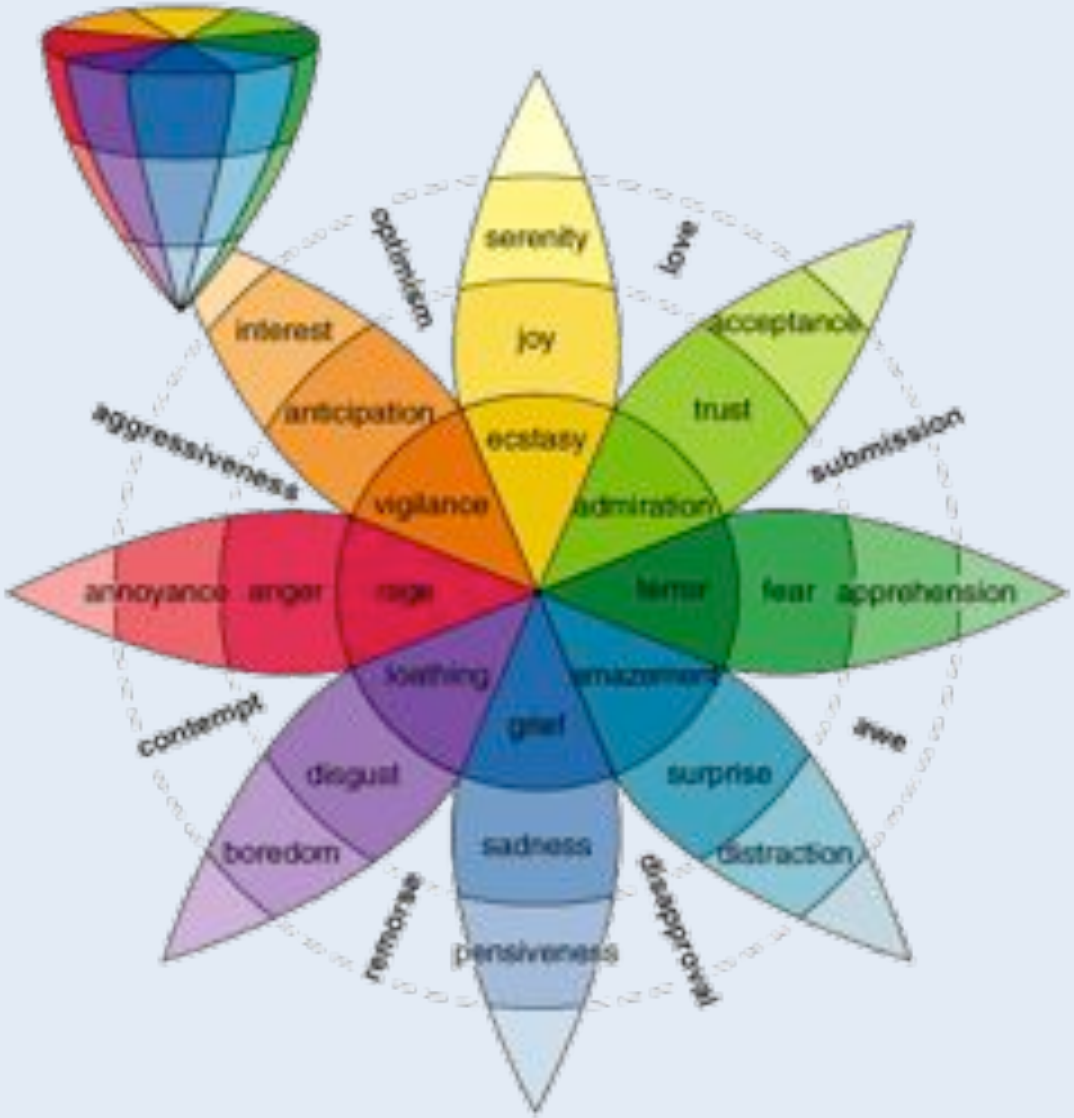
S Makeig, 2013

Folding the Enharmonic Tone Group into the 12-note torus



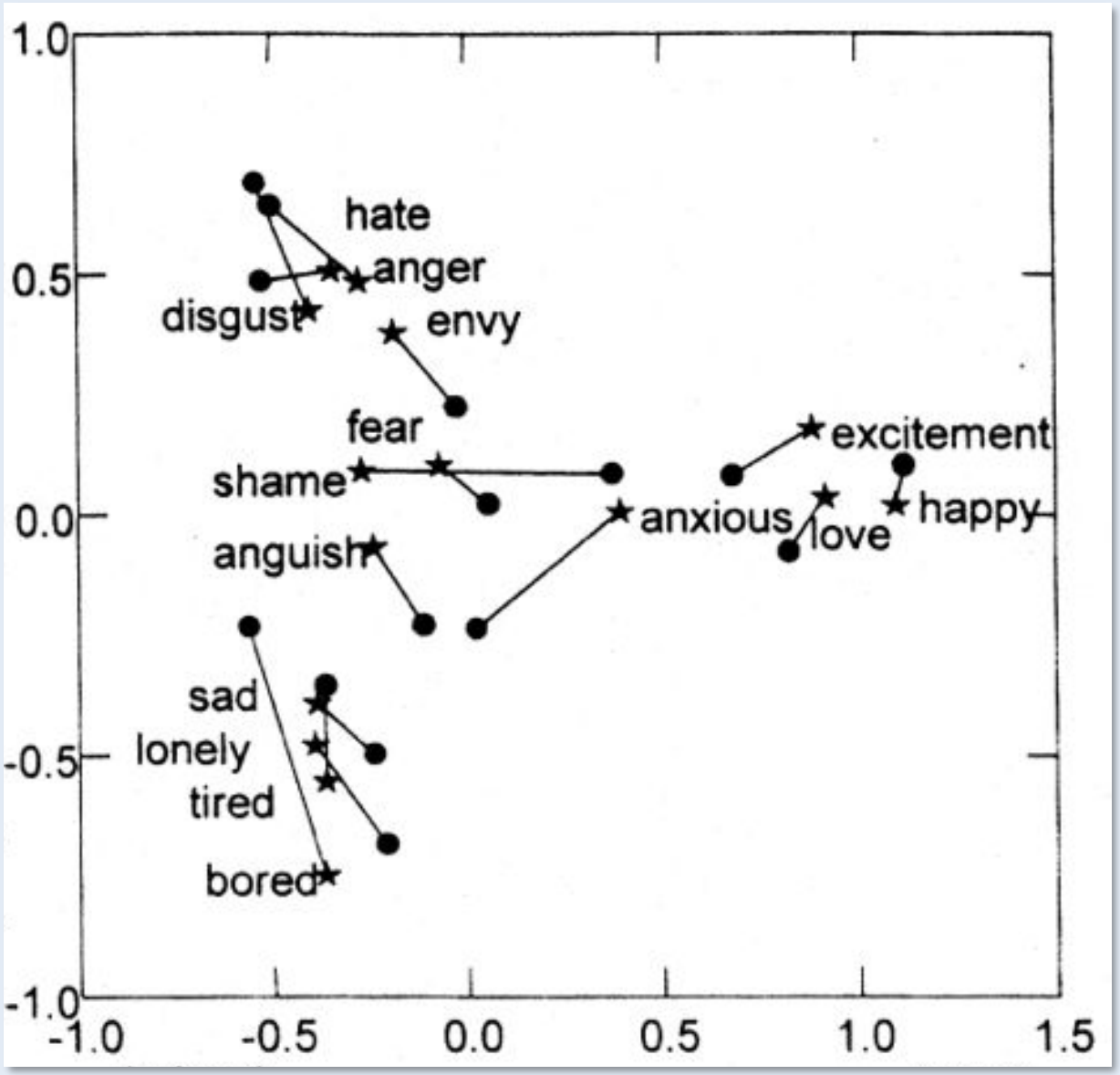
S Makeig, 2013

One Affect-Space Concept



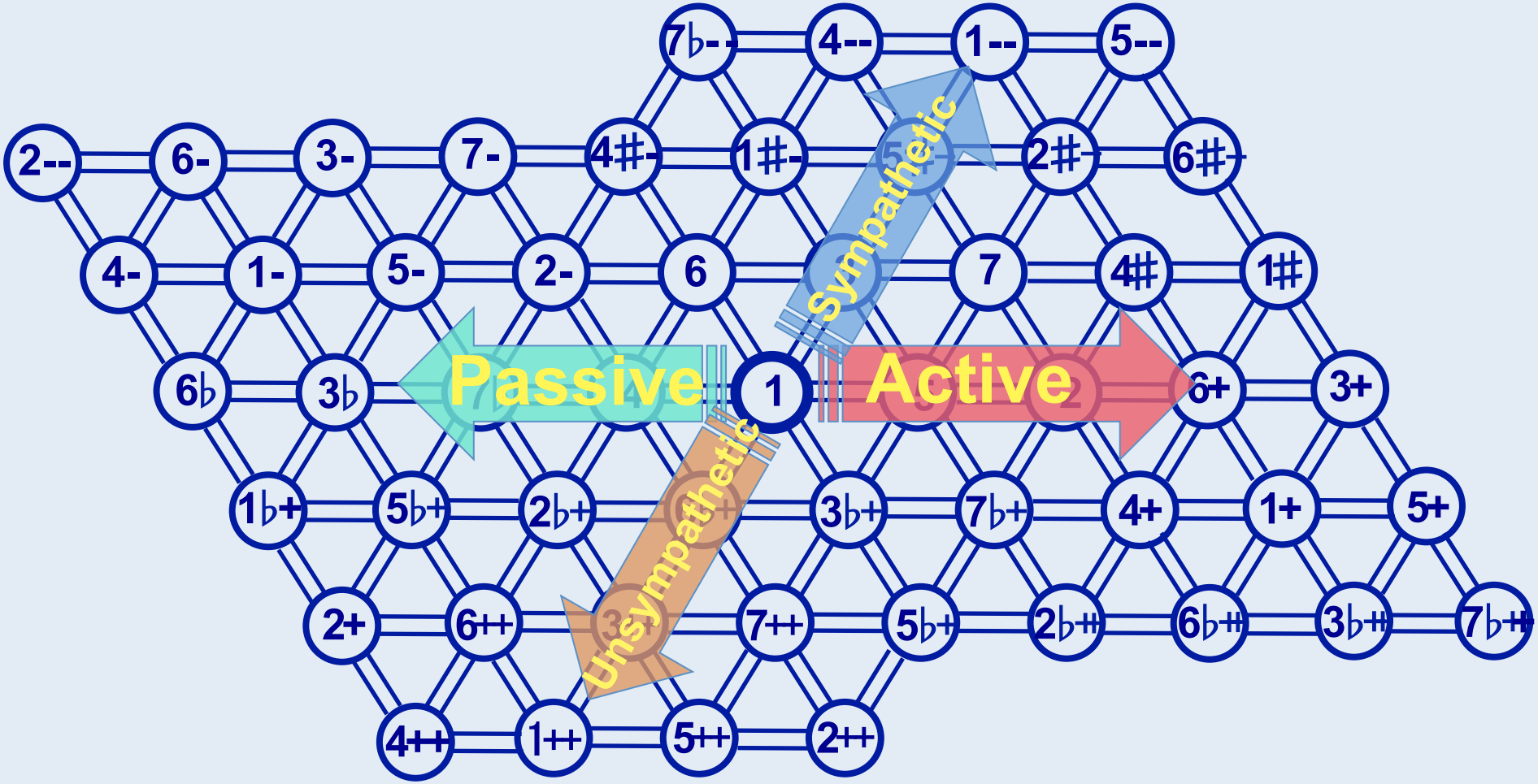
Plutchik, R. (2003). Emotions and life: Perspectives from psychology, biology, and evolution.

The Semantic Differential



S Makeig, 2013

The Harmonic Tone Group

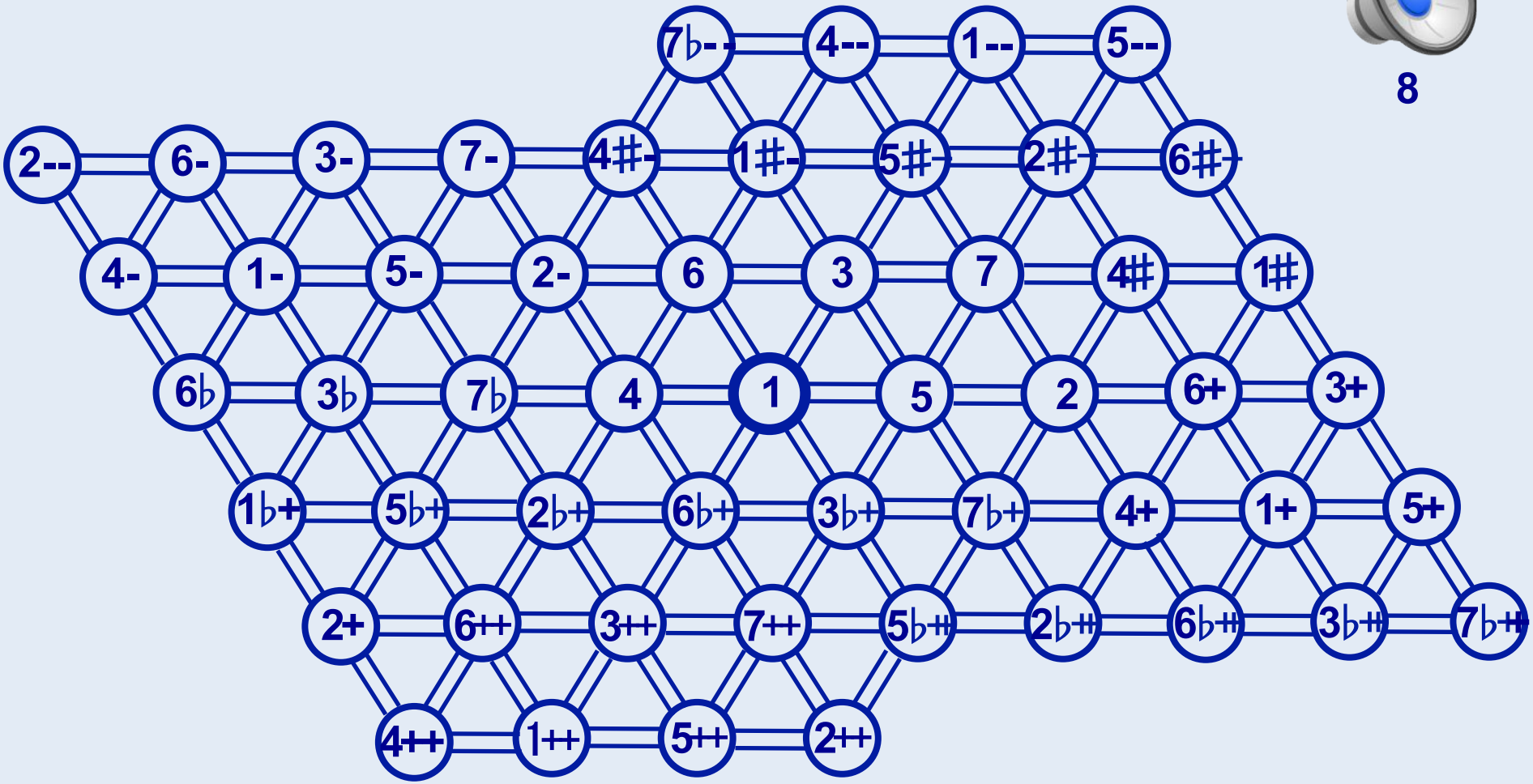


After Alain Danielou – theory of interval affect

S Makeig, 2013

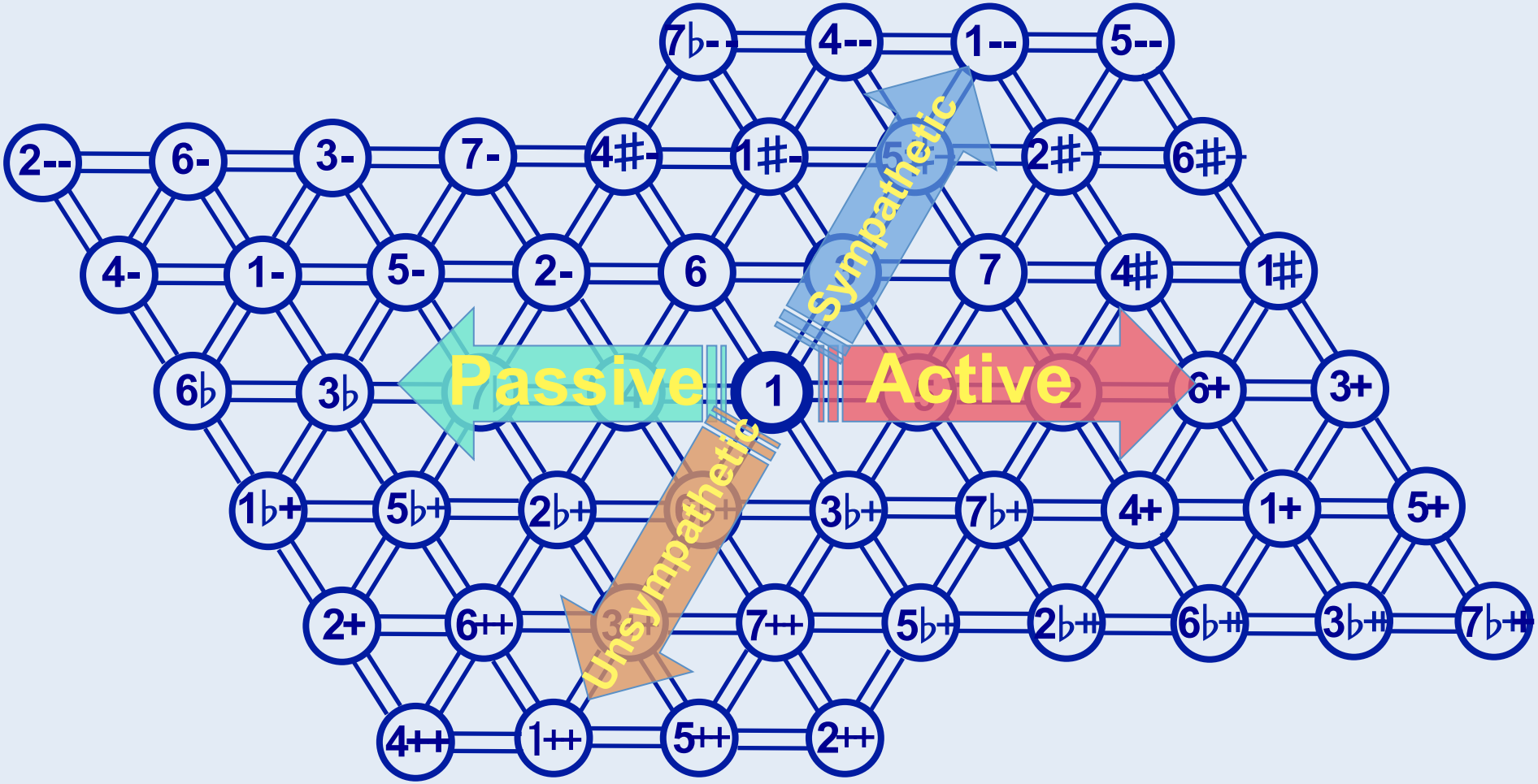
The Web of Musical Fifths (3/2) and Thirds (5/4)

8



S Makeig, 2013

The Harmonic Tone Group



After Alain Danielou – theory of interval affect

S Makeig, 2013

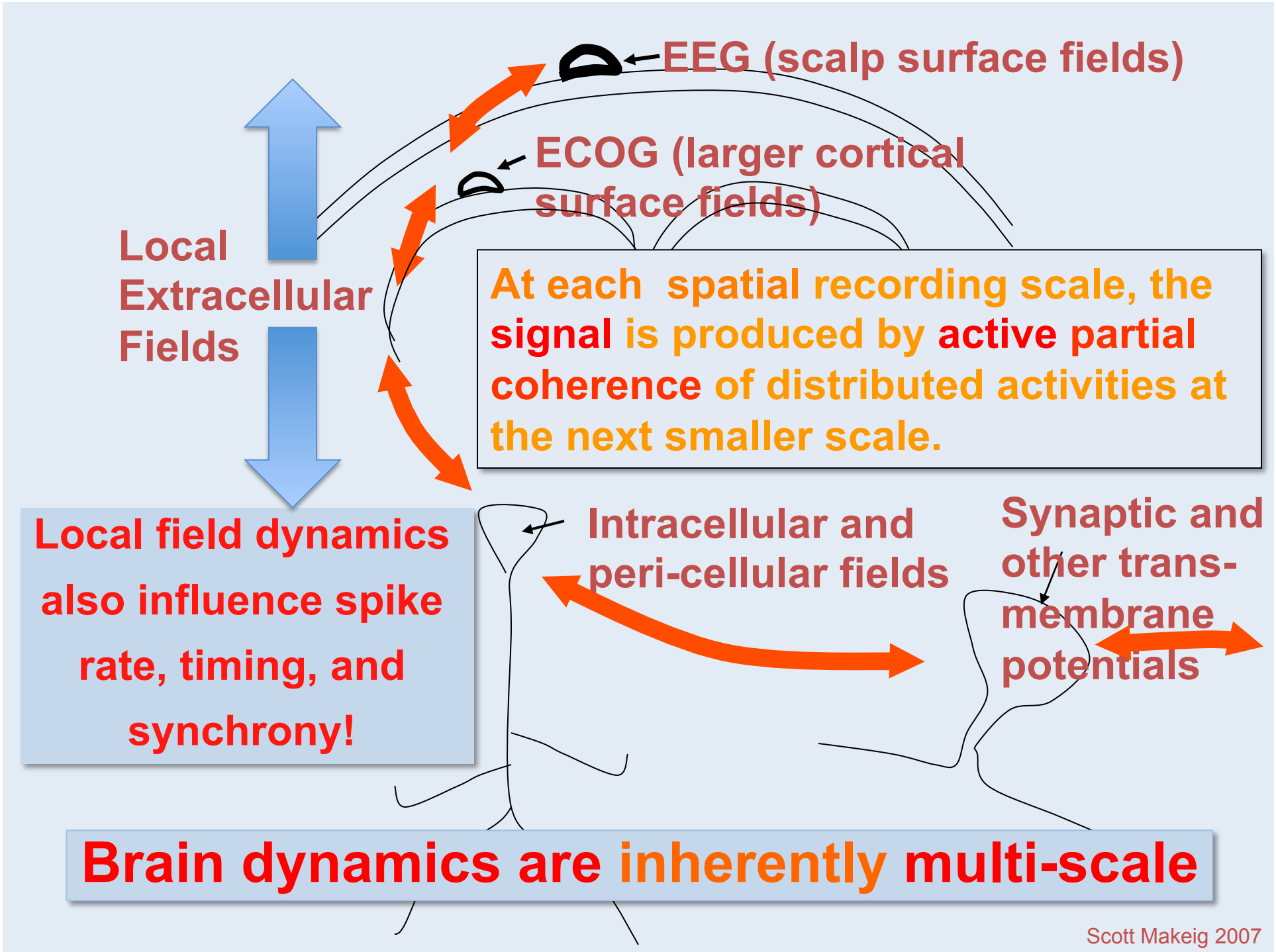
What is EEG?

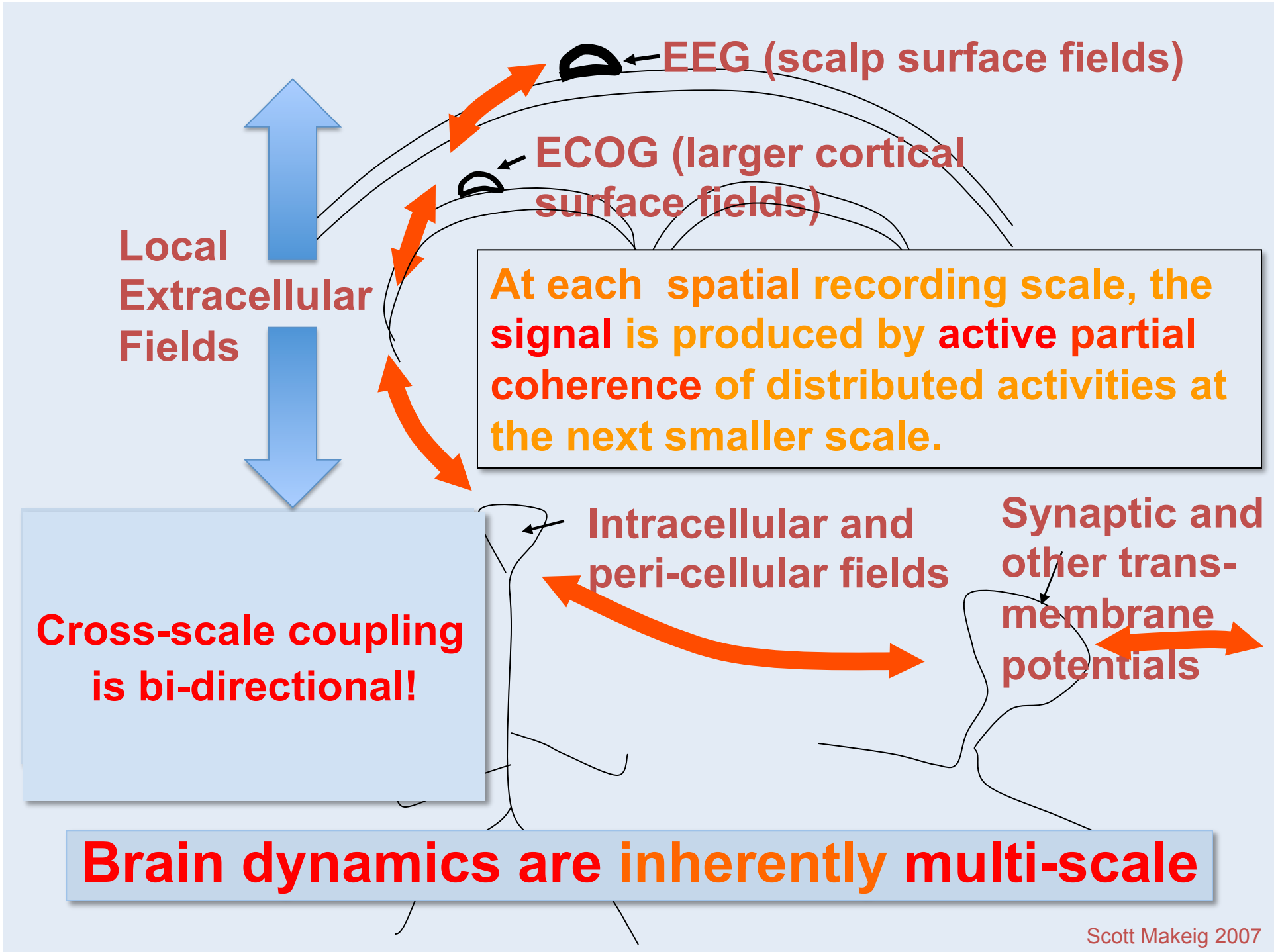
EEG?

- Brain electrical activity
- A small portion of *cortical* brain electrical activity
- An even smaller portion of *total* brain electrical activity

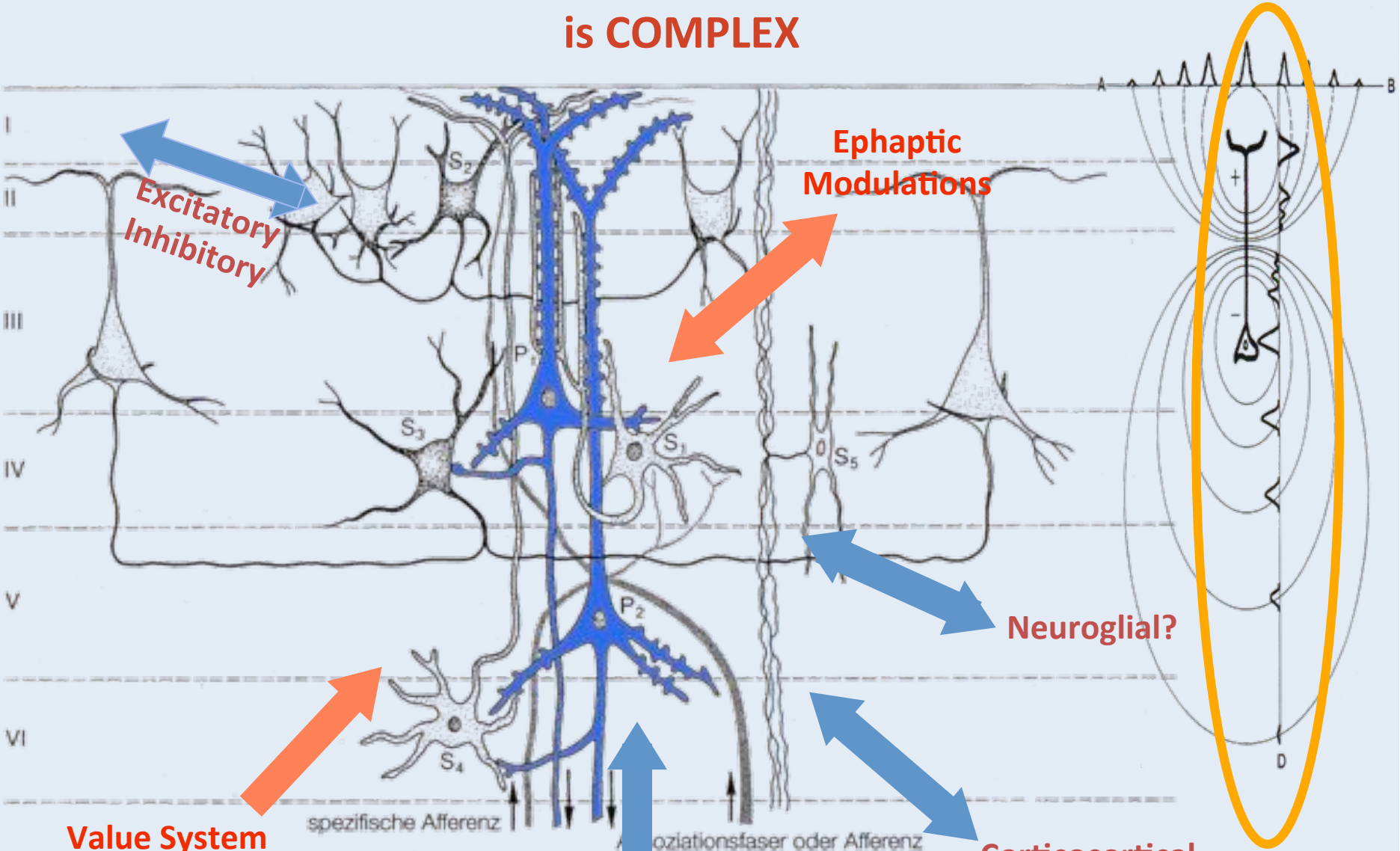
- **But *which* portion?**
- **Triggered and modulated *how*?**
- **With *what* functional significance?**

Cloud art: Berndnaut

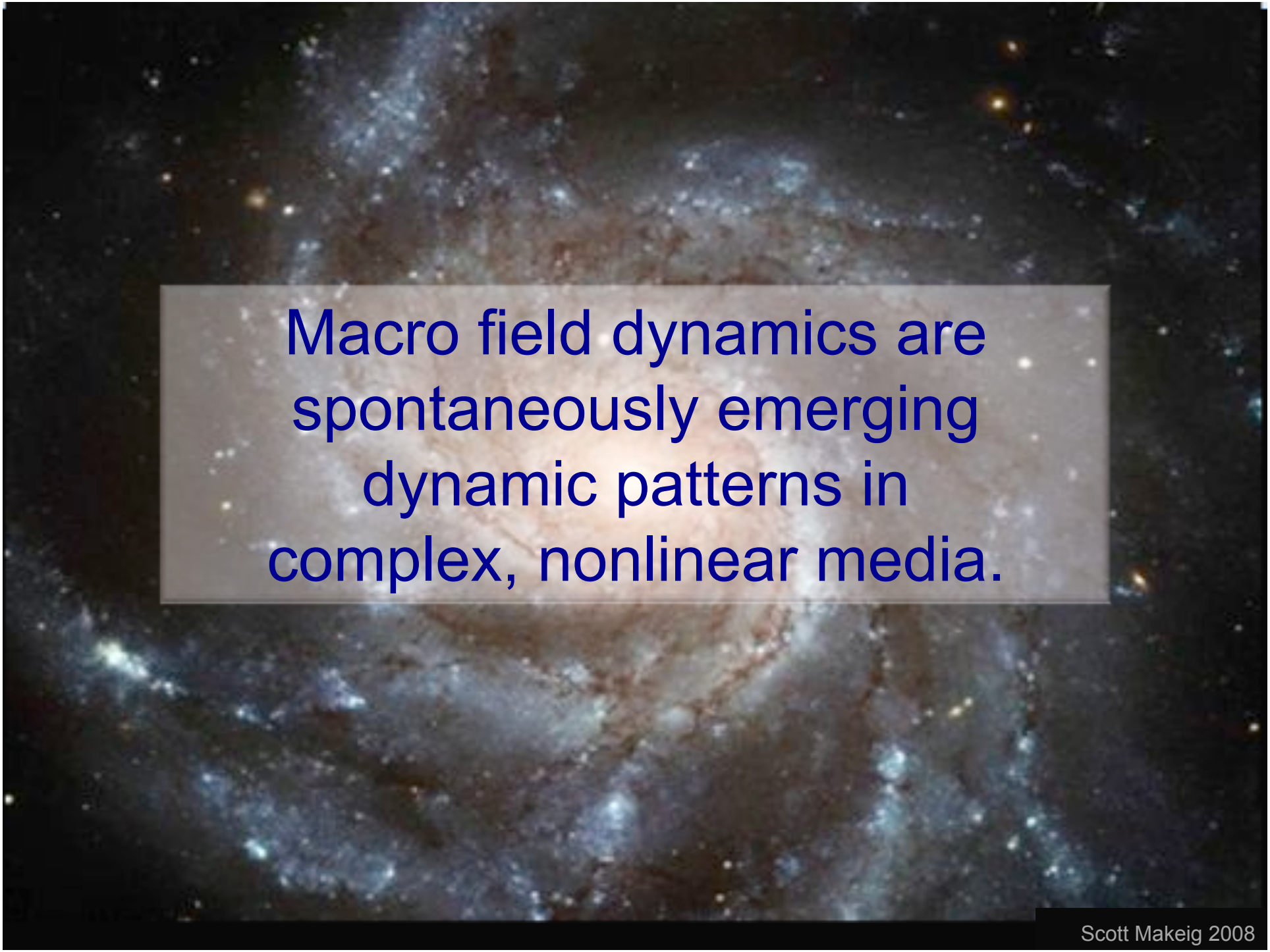

EEG (scalp surface fields)
ECOG (larger cortical surface fields)
Local Extracellular Fields
At each spatial recording scale, the signal is produced by active partial coherence of distributed activities at the next smaller scale.
Local field dynamics also influence spike rate, timing, and synchrony!
Intracellular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


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.
Intracellular and peri-cellular fields
Synaptic and other trans-membrane potentials
Cross-scale coupling is bi-directional!
Brain dynamics are inherently multi-scale
Scott Makeig 2007

The generation and modulation of EEG / LFP is COMPLEX



S. Makeig 2007


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

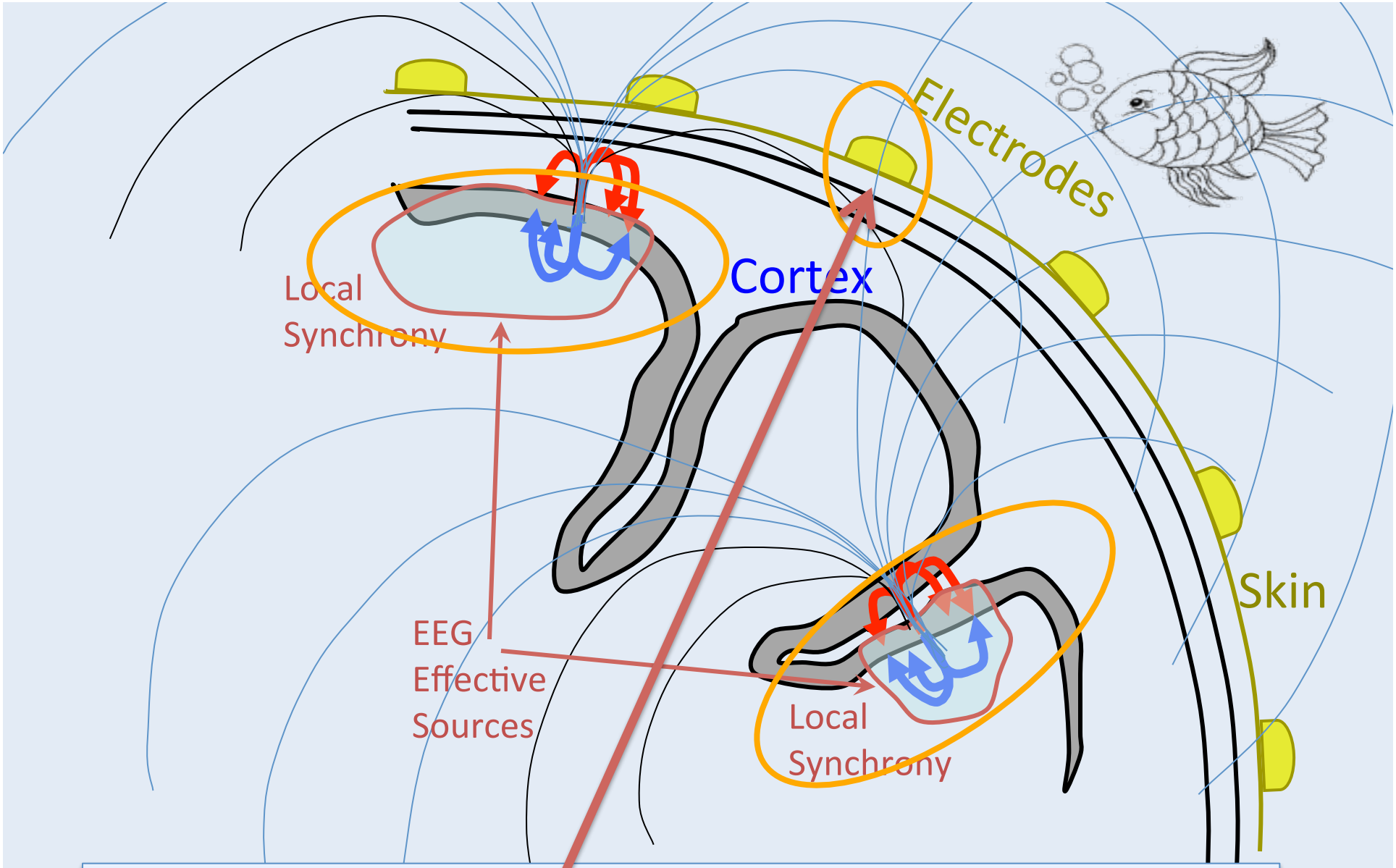
The spatiotemporal field dynamics of cortex have not yet been imaged simultaneously on multiple spatial scales!

Alan Friedman

Phase cones (Freeman)

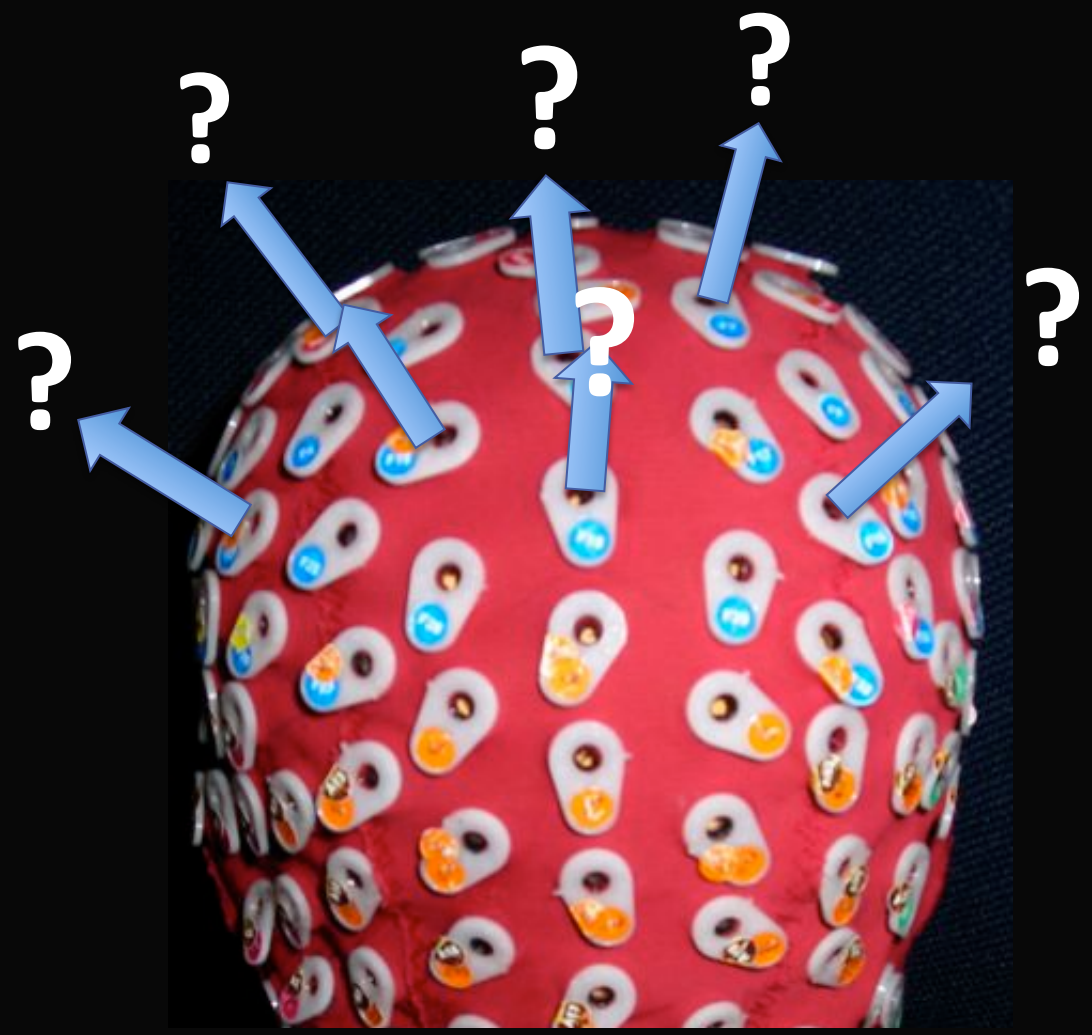
Avalanches (Beggs & Plenz)

S. Makeig 2007



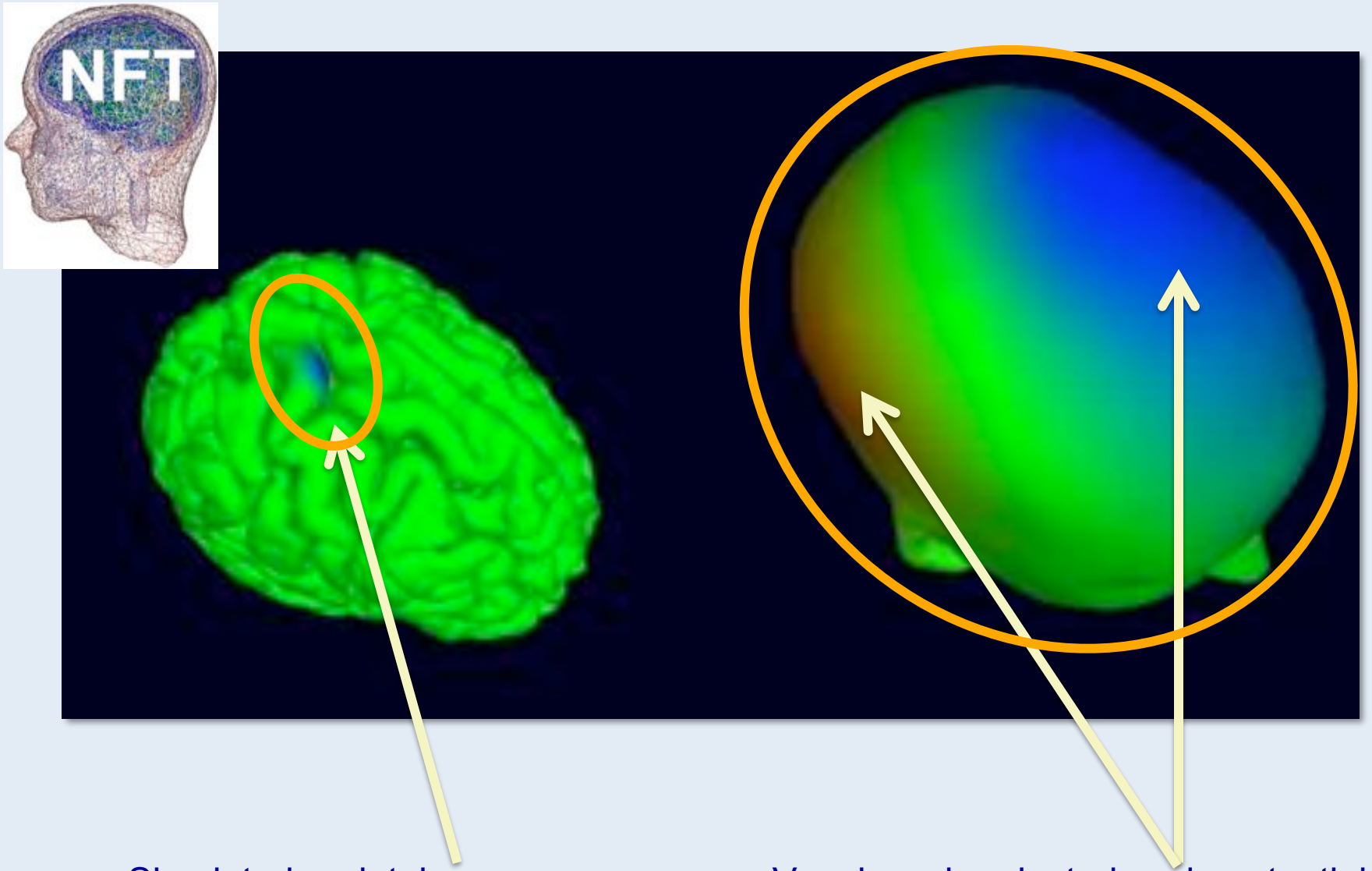
Each scalp EEG data channel sums the projected activities of multiple brain (and non-brain) source processes.

S. Makeig 2007



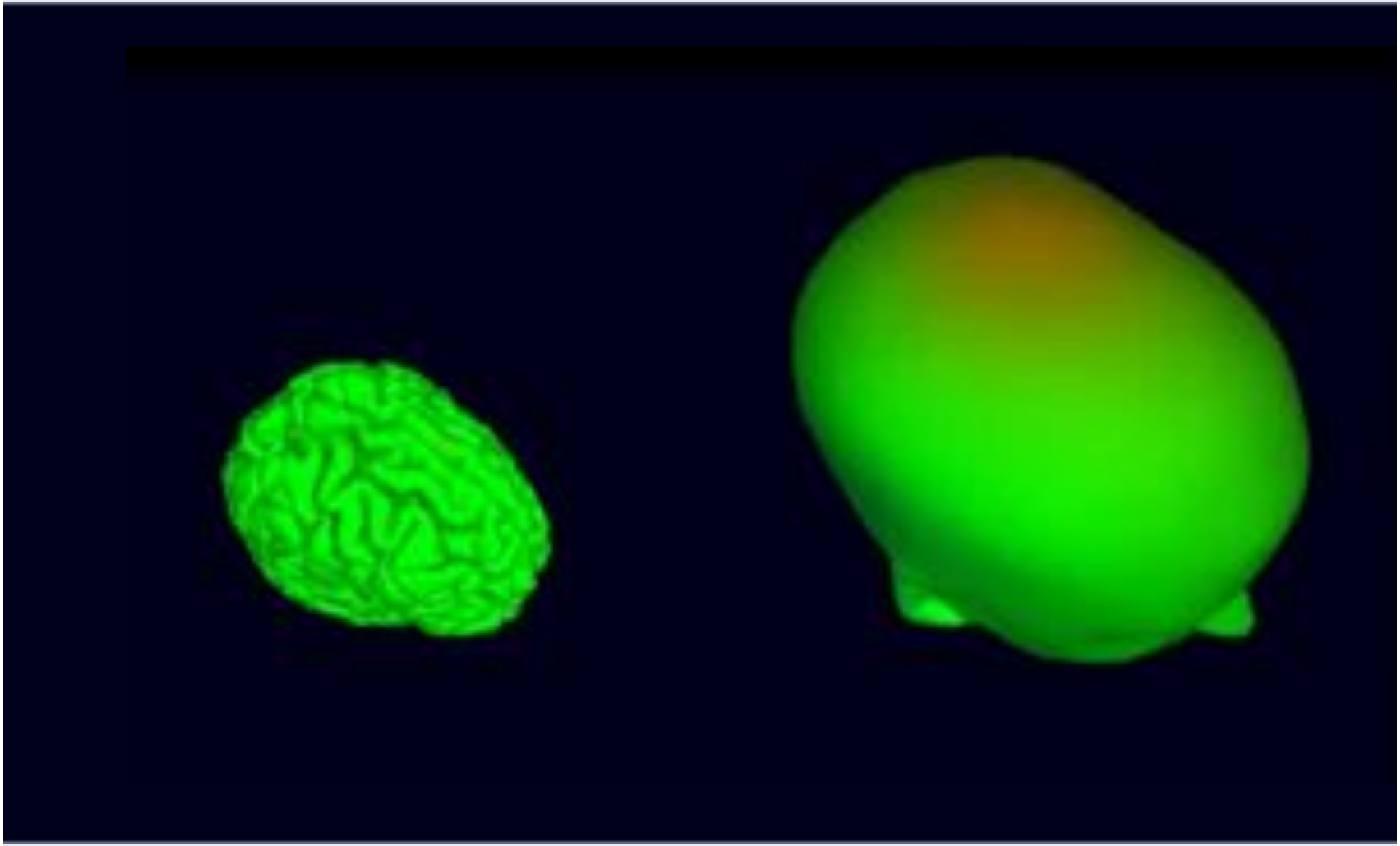
The EEG Fallacy

The very broad EEG point-spread function



Akalin Acar & Makeig 2010

The very broad EEG point-spread



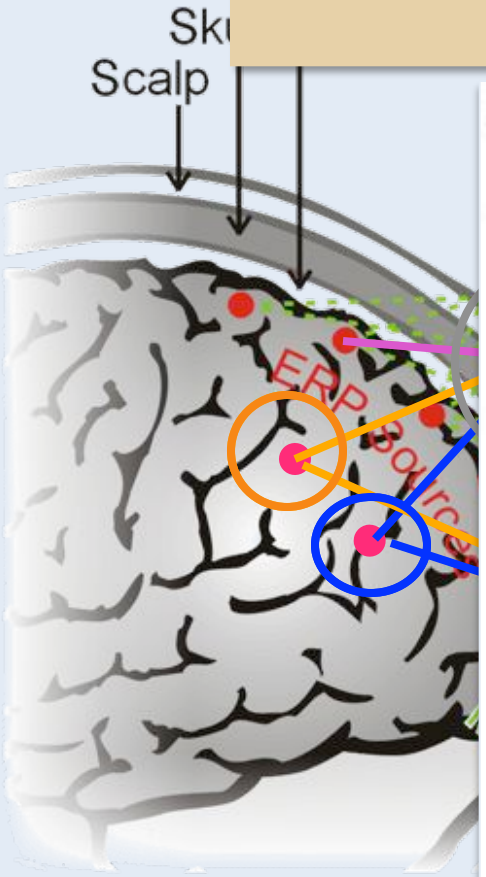
Simulated cm^2-scale two-source activity and its summed EEG projection

Akalin Acar & Makeig 2012

Blind EEG Source Separation by Independent Component Analysis

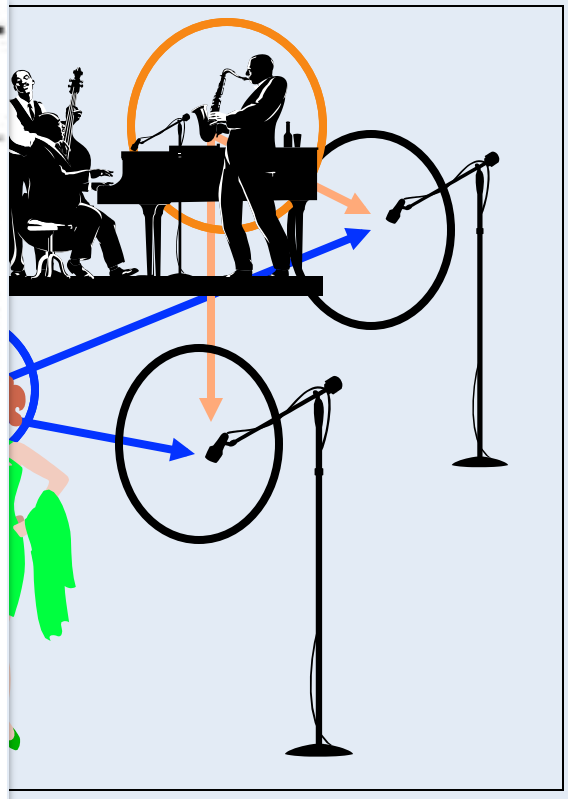
Tony Bell, developer of Infomax ICA

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



Independent Component Analysis of Electroencephalographic Data

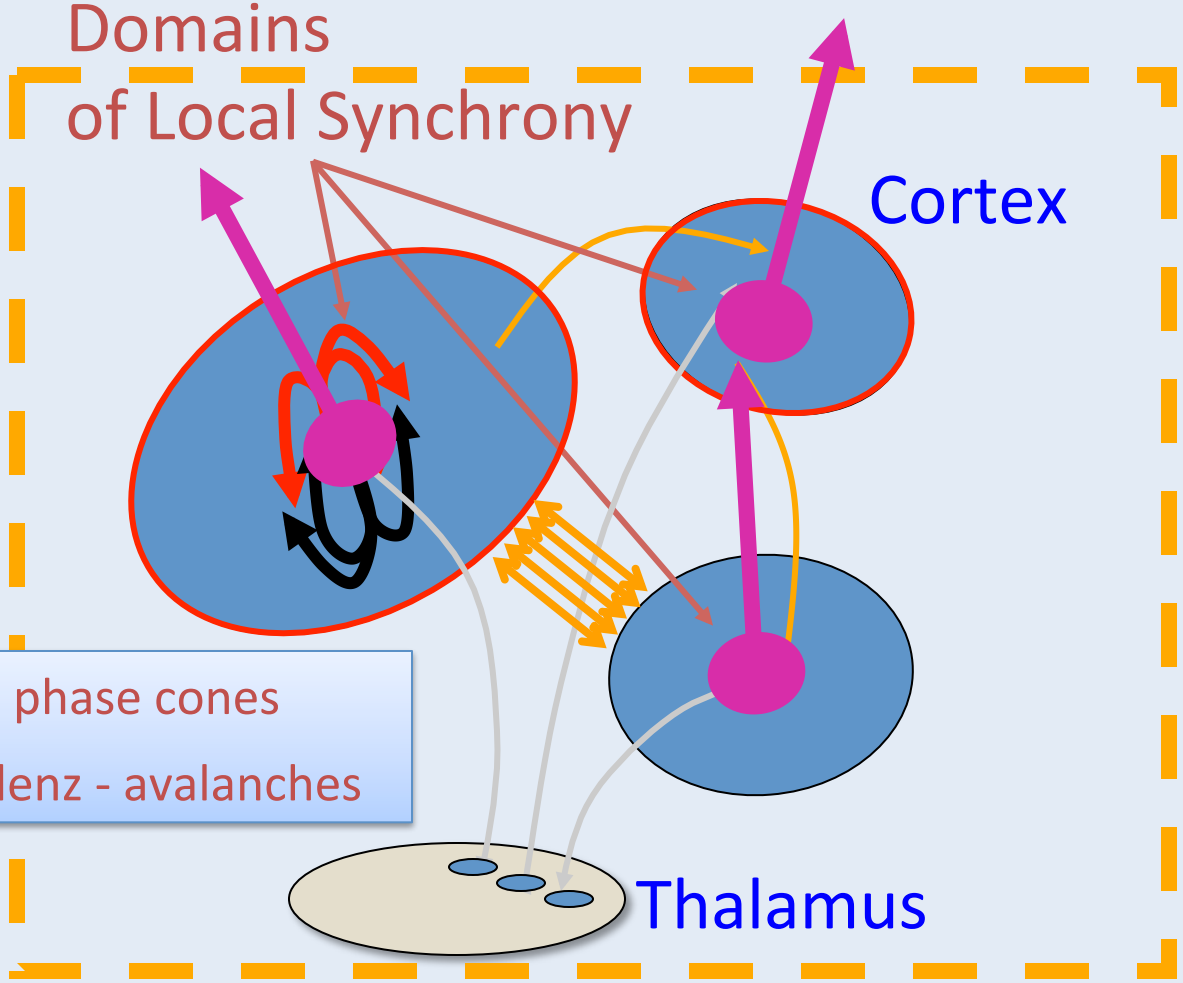
Abstract



S. Makeig, S. Enghoff (2000)

Are EEG source outputs (near) independent?

Independent
Domains
of Local Synchrony

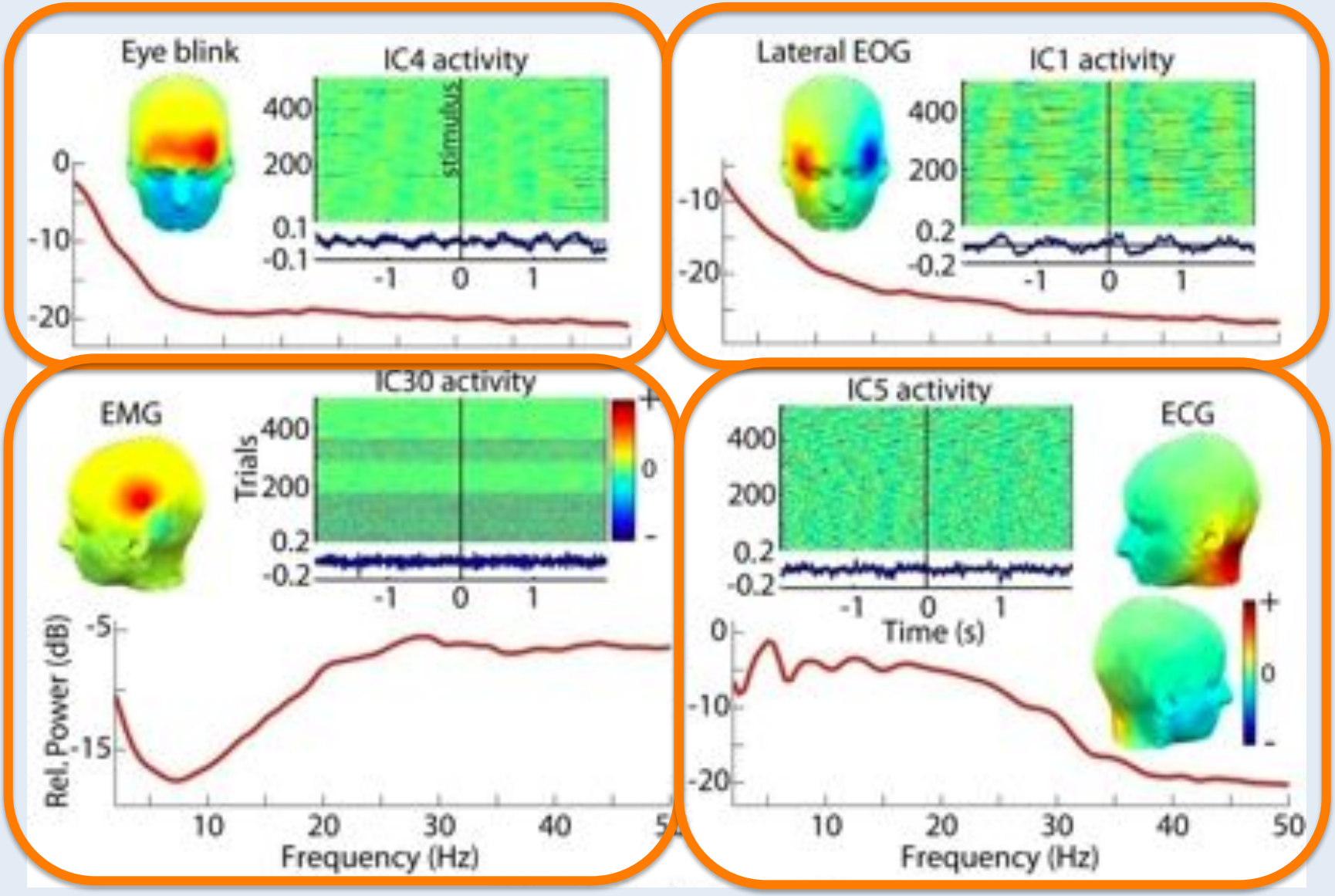


Freeman - phase cones

Beggs & Plenz - avalanches

S. Makeig (2007)

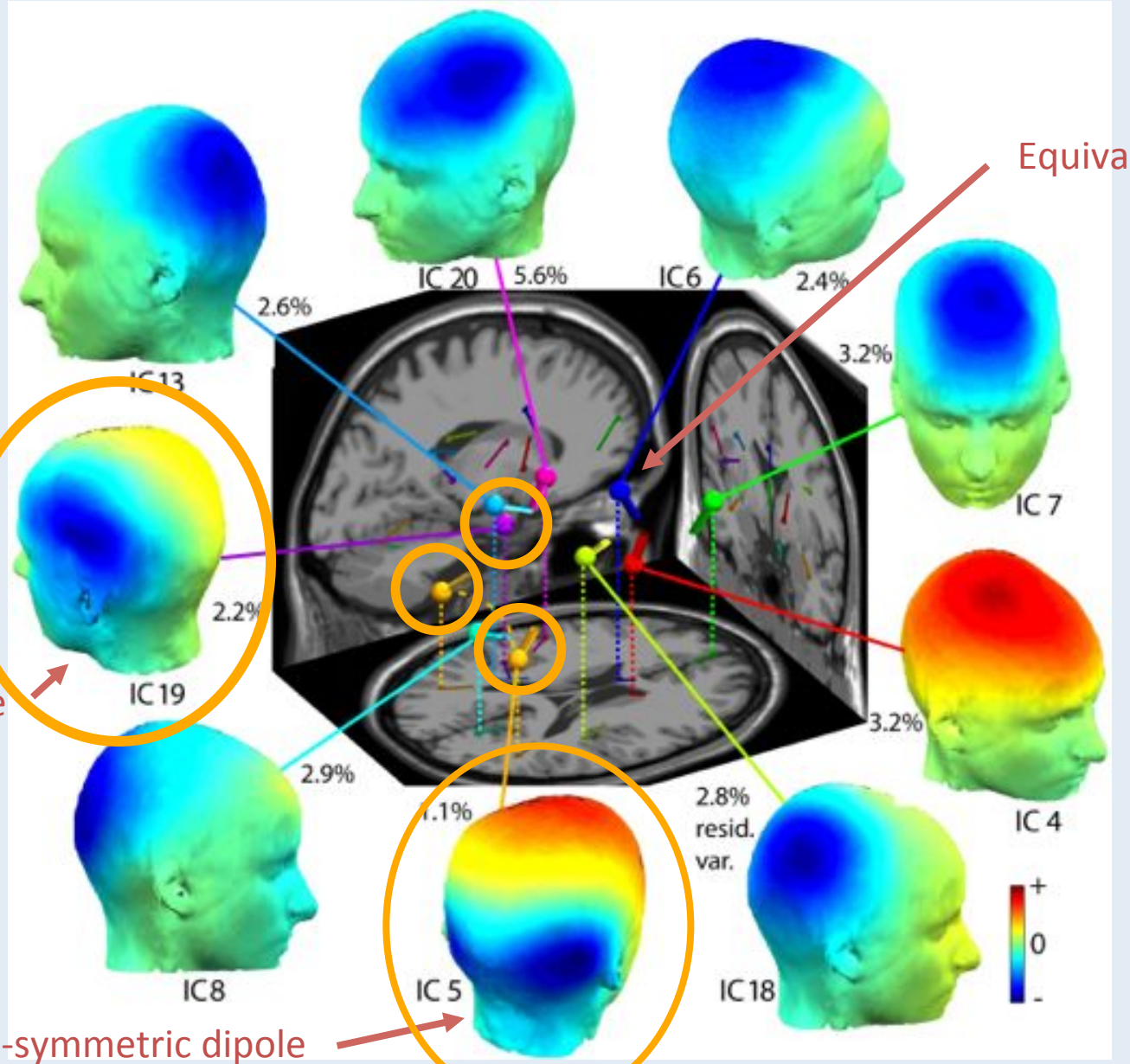
ICA finds Non-Brain Independent Component (IC) Processes …



… separates them from the remainder of the data …

J. Onton & S. Makeig 2006

ICA also separates cortical brain IC processes



Equivalent dipoles

Single dipole component

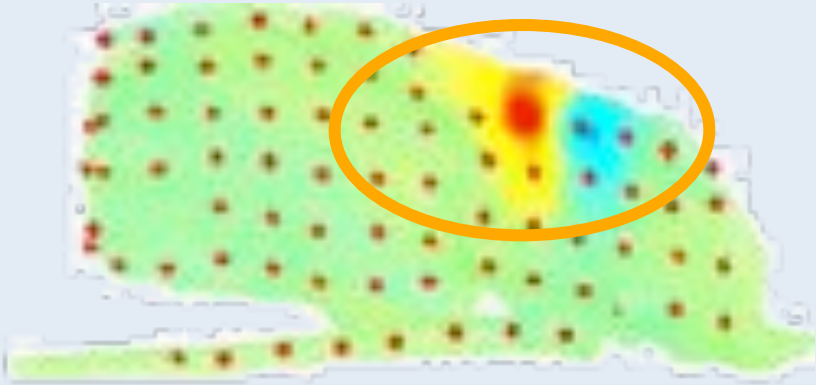
Dual-symmetric dipole component

Julie Onton & S. Makeig (2006)

Patch-basis localization of independent component sources

Scalp EEG source

iEEG sulcal seizure source

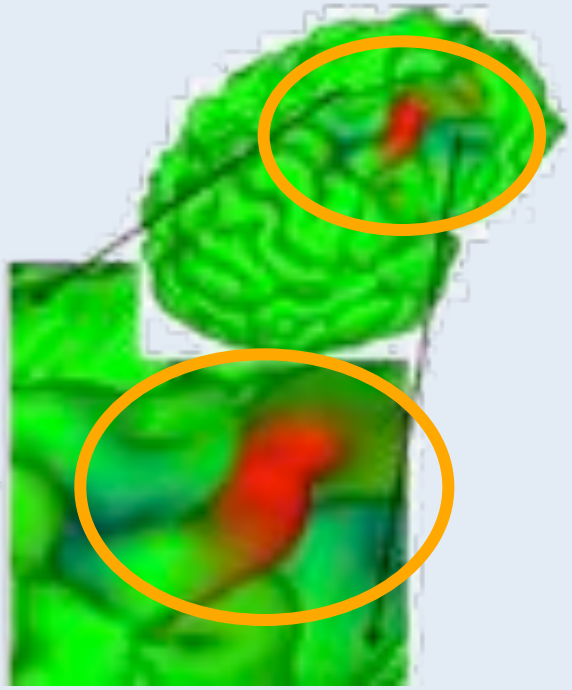


FEASIBLE FOR SCALP EEG ICs?

Will need at least:

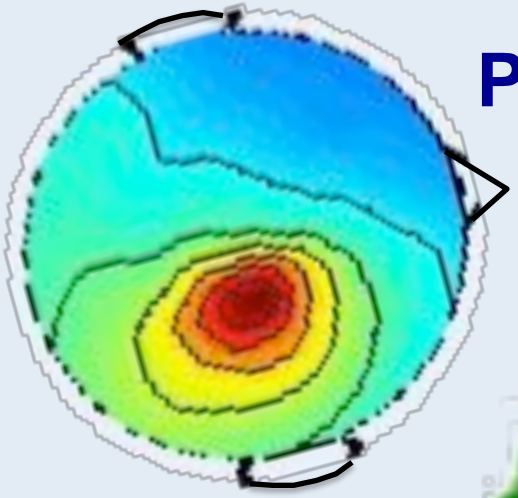
- Anatomic MR image
- Accurate electrode positions
- Accurate co-registration
- **Good skull conductivity estimate**

IC source domain estimate



Z. Akalin Acar, S. Makeig, 2011

Patch-basis source localization

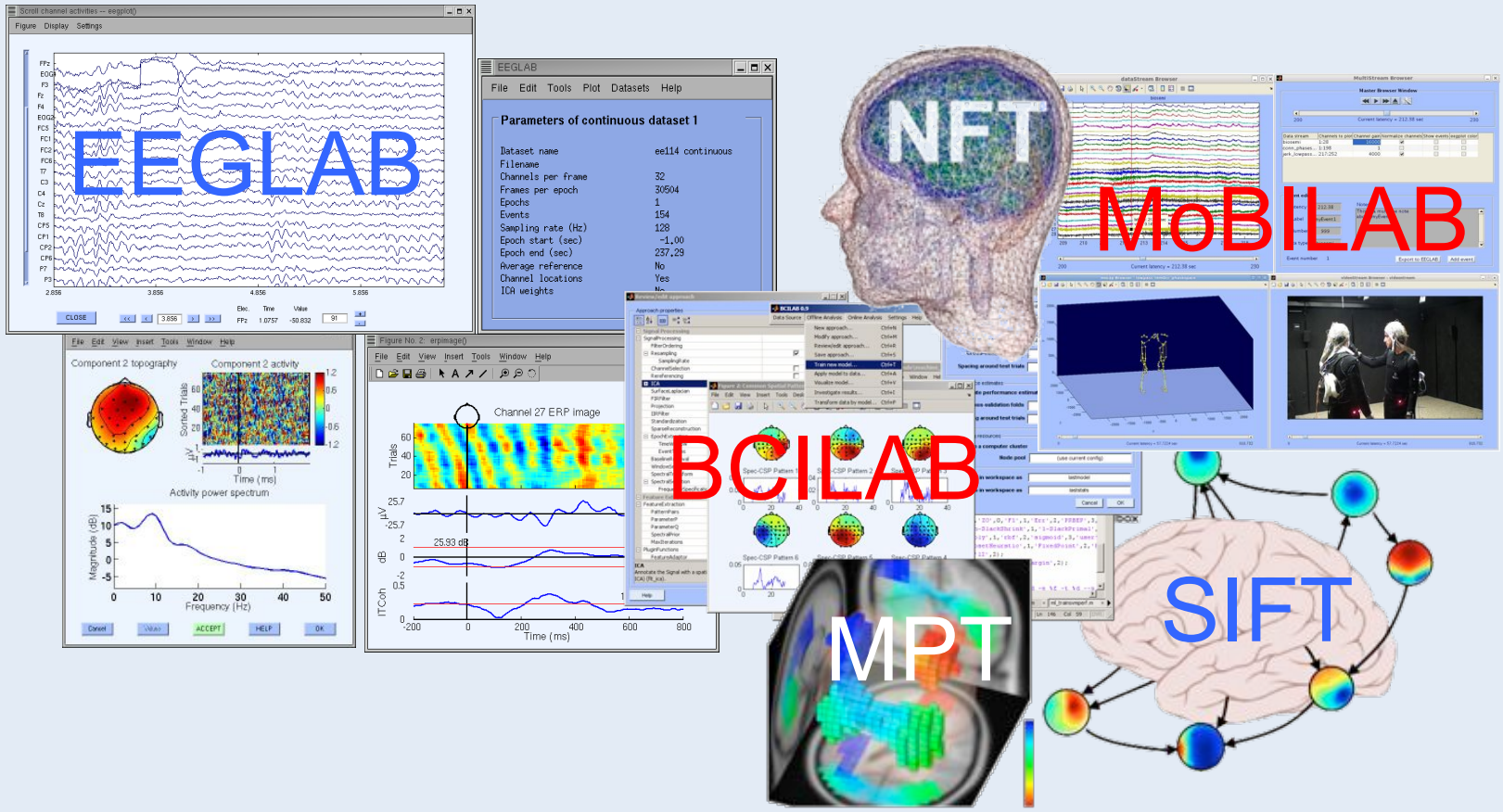


IC

Swartz Center for Computational Neuroscience

Z. Akalin Acar & S. Makeig, 2013

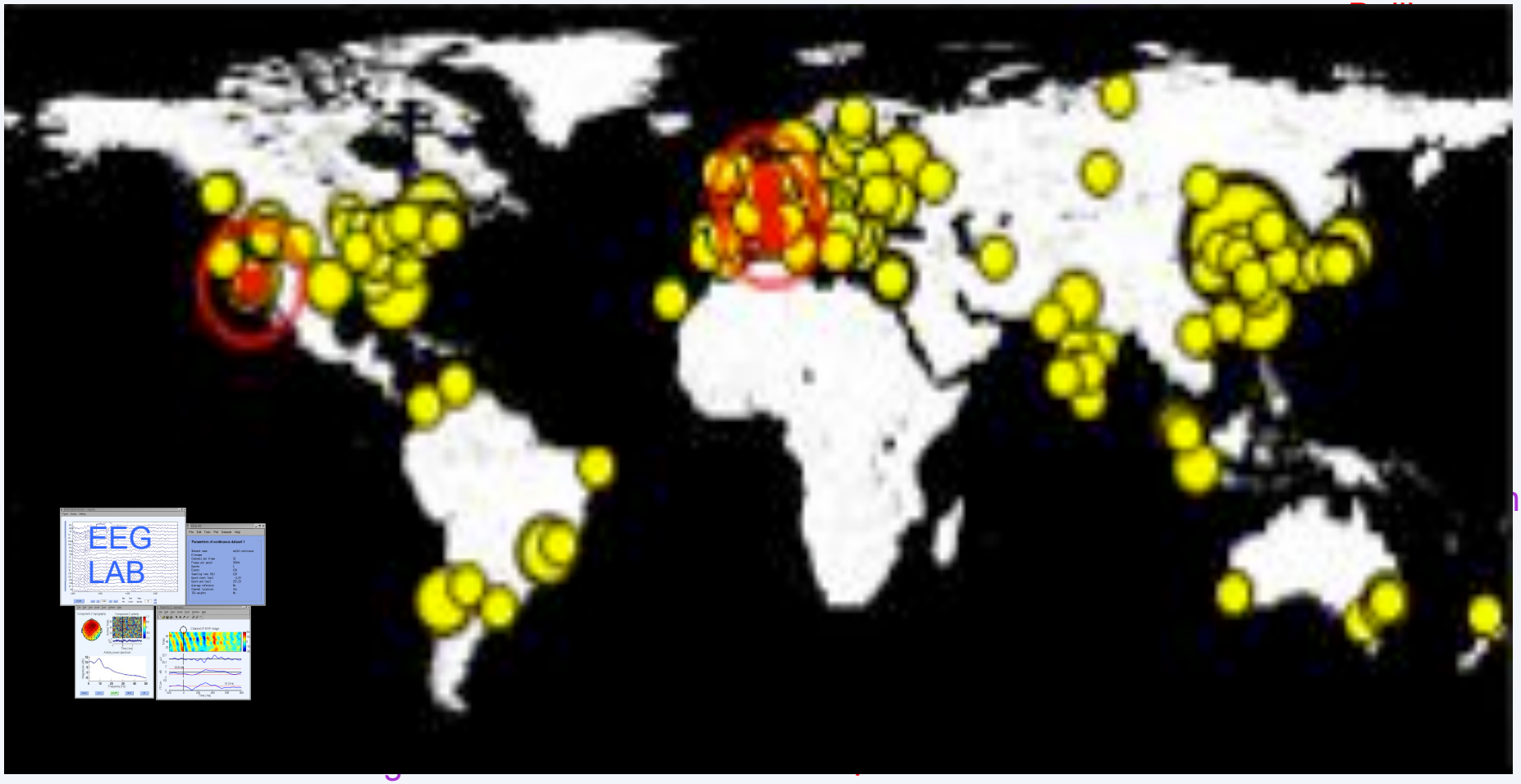
SCCN Open Source Software Tools for MATLAB



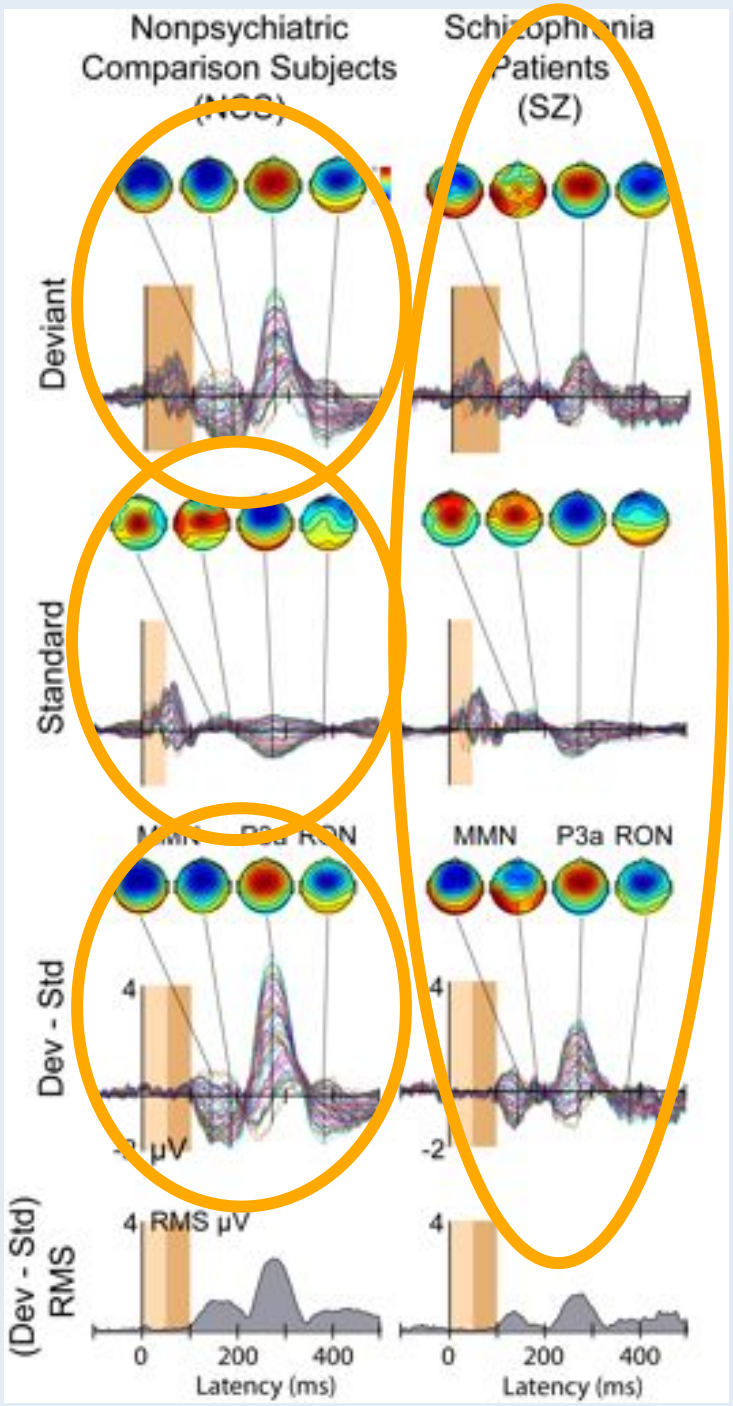
Tools available -- but a ‘two cultures’ problem …

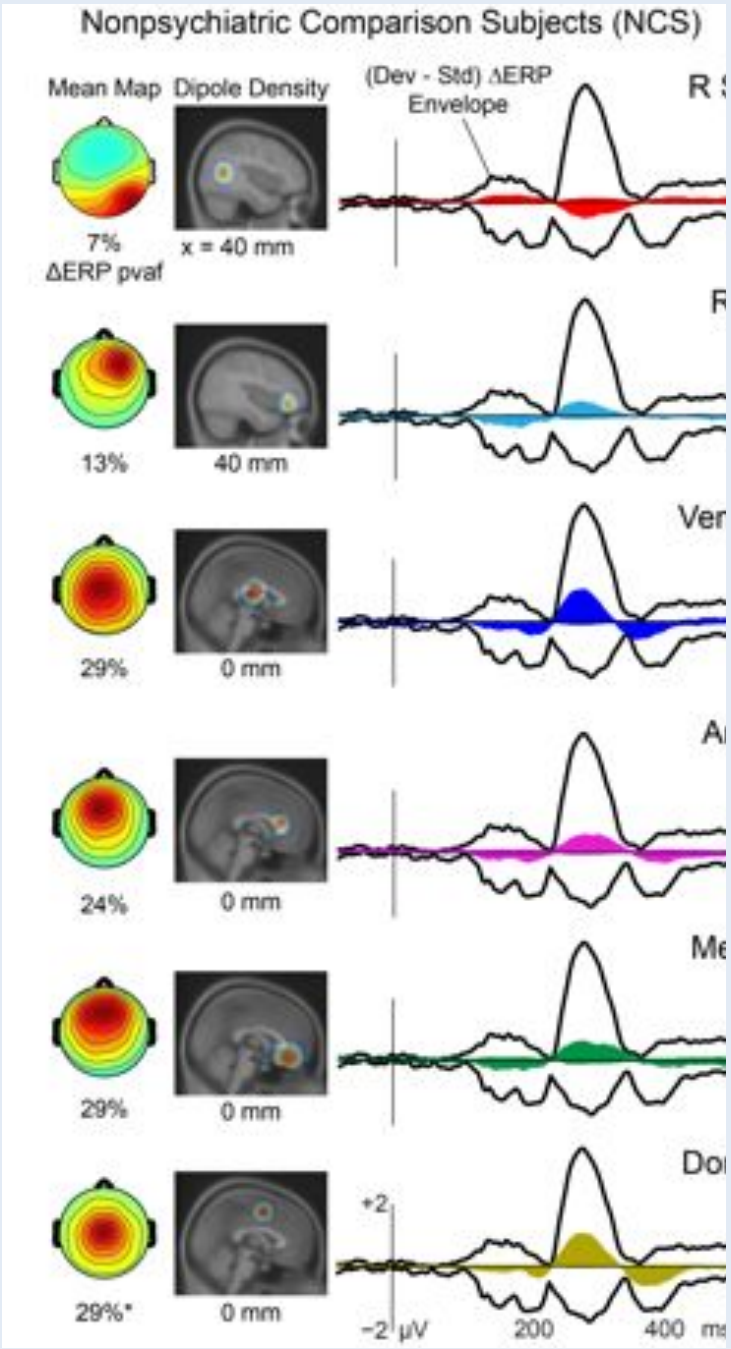
S Makeig, 2012

EEGLAB Home page visitors (one 24-hr period)

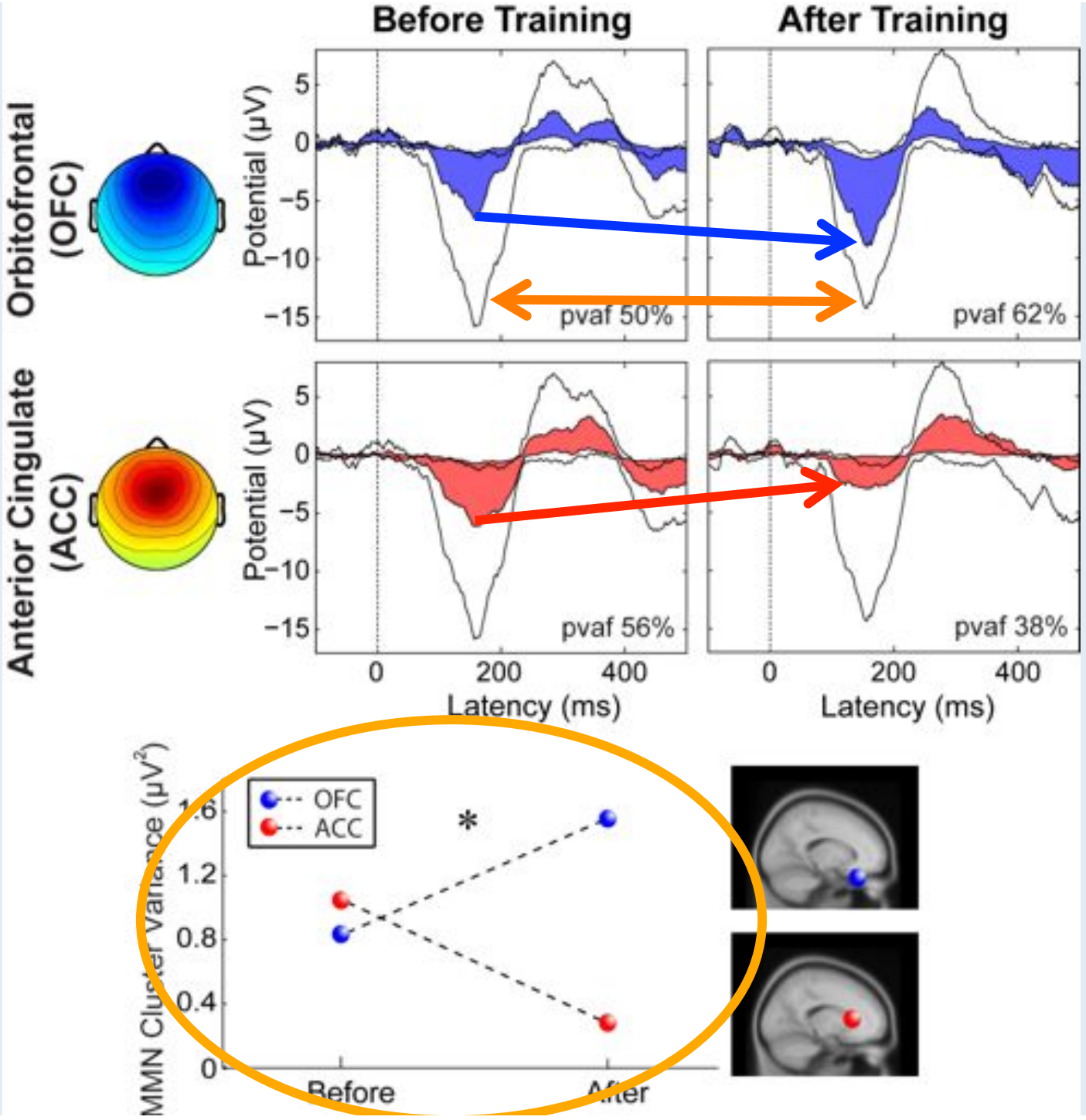


S. Makeig 2011





Rissling, Miyakoshi, Makeig, Light, submitted


Before Training
After Training
Orbitofrontal (OFC)
Anterior Cingulate (ACC)
Potential (μV)
5
0
−5
−10
−15
pvaf 50%
pvaf 62%
pvaf 56%
pvaf 38%
0
200
400
Latency (ms)
OFC
ACC
*
1.2
0.8
0.4
0
Before
After

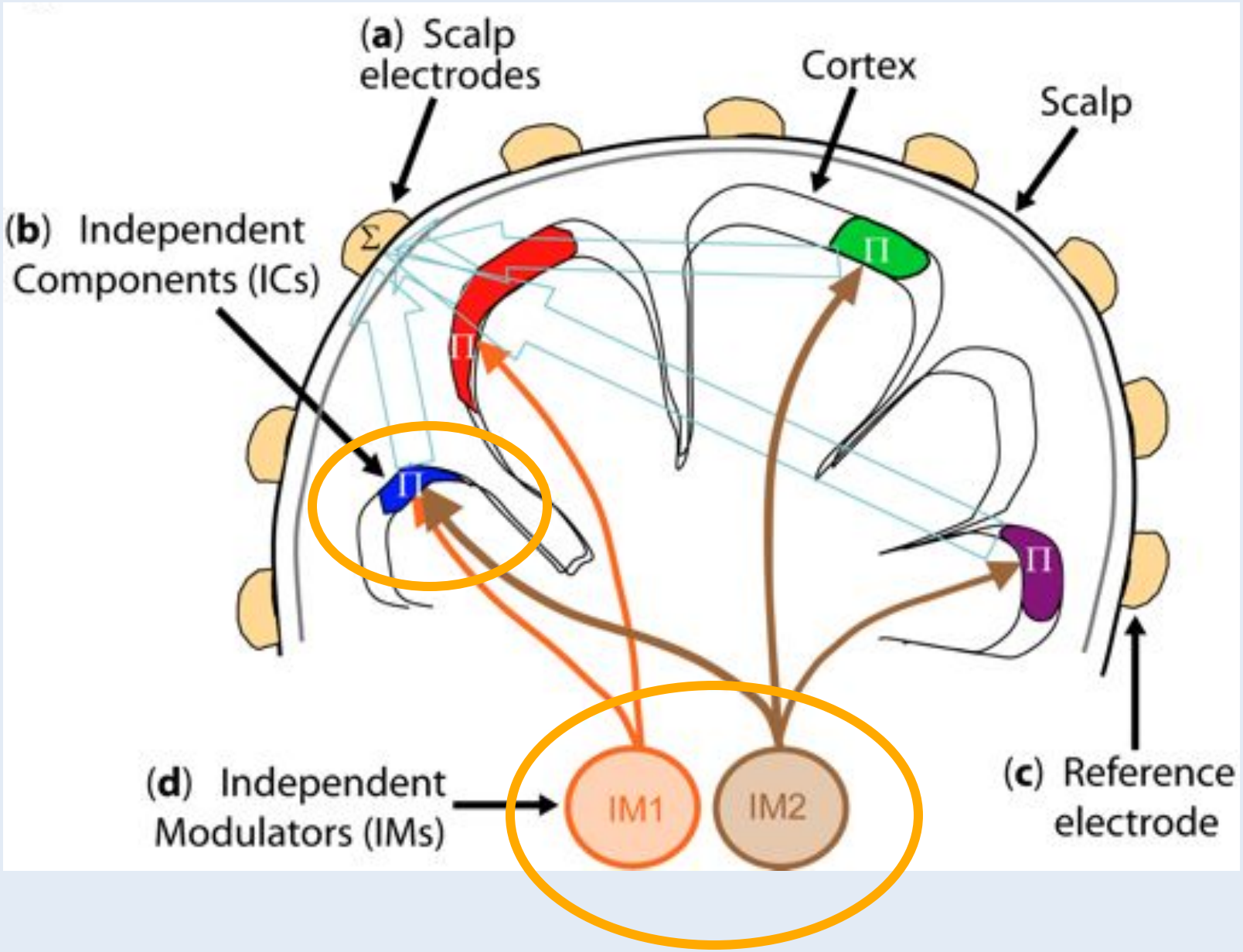
EEG Dynamics of Emotion Imagination

Suggest the imaginative experience of 15 emotions:

- After Helen Bonny (GIM)
- Preceding relaxation induction
- Alternate pos and neg emotions
- Relax between emotion episodes
- **→1-5 min periods of eyes-closed spontaneous EEG** (x 15 emotions)
- From 33 subjects

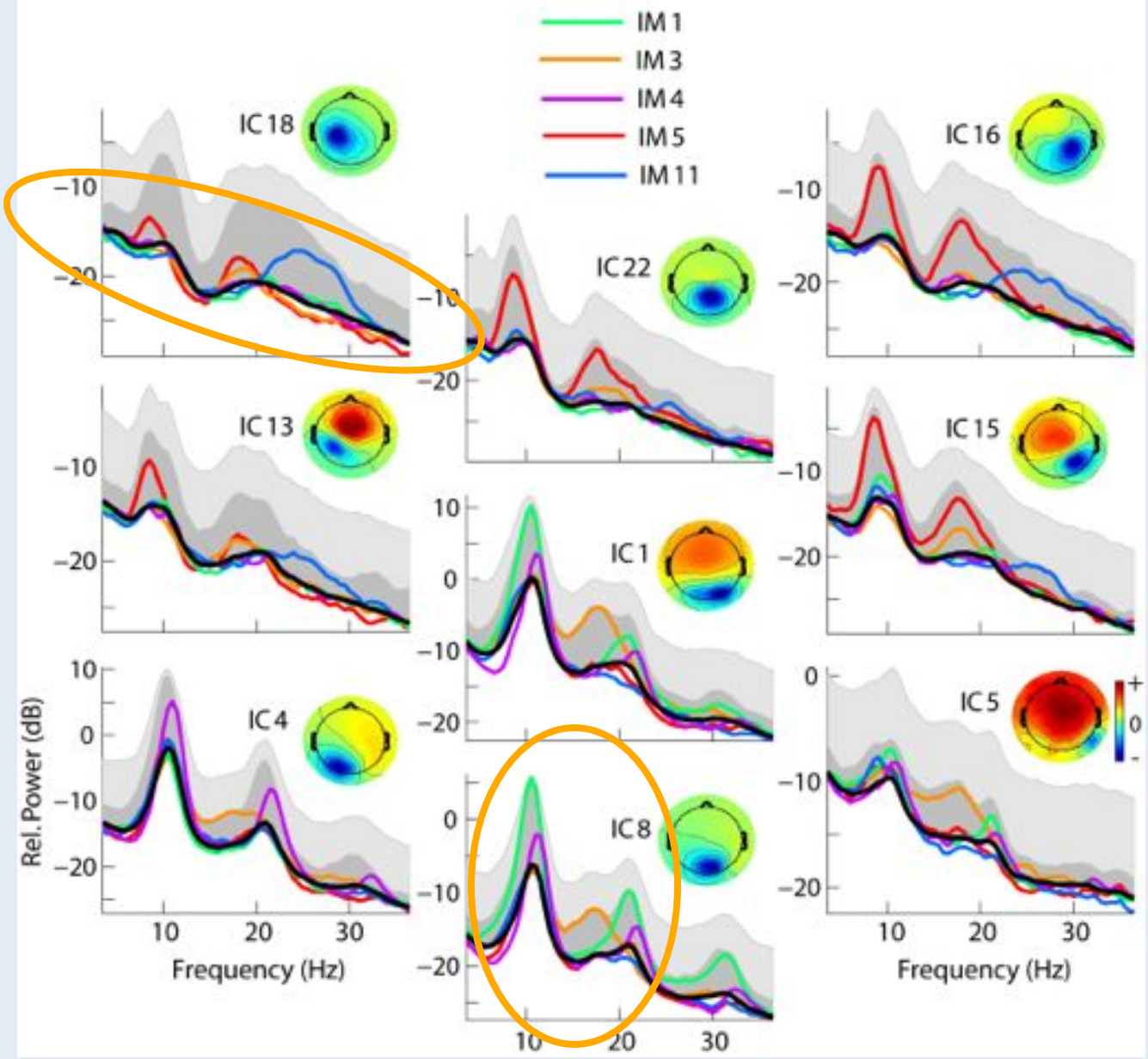
Onton & Makeig, *Frontiers in Human Neuroscience* '09

Independent Modulators



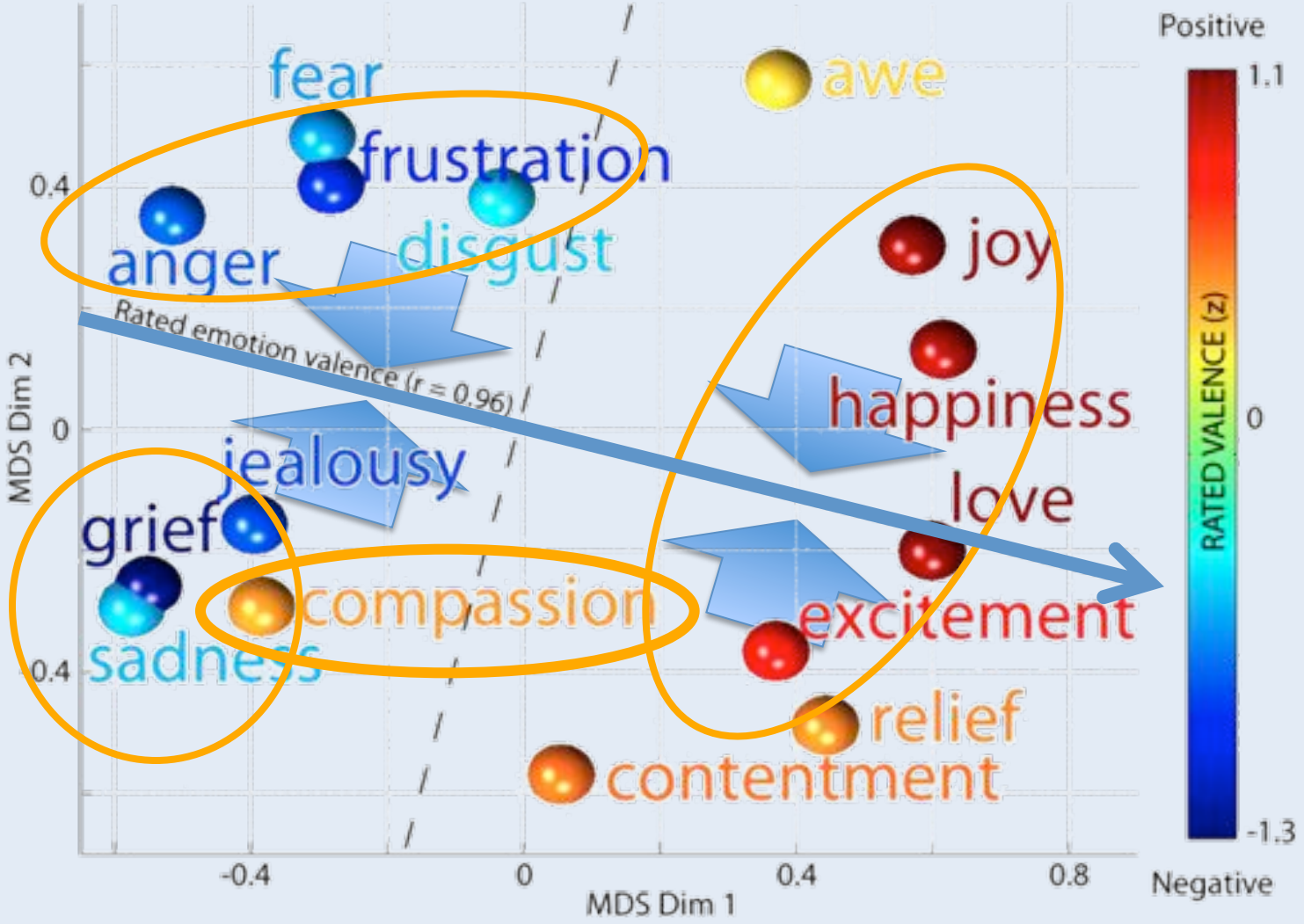
Onton & Makeig, *Frontiers in Human Neuroscience* '09

Independent modes of spectral modulation

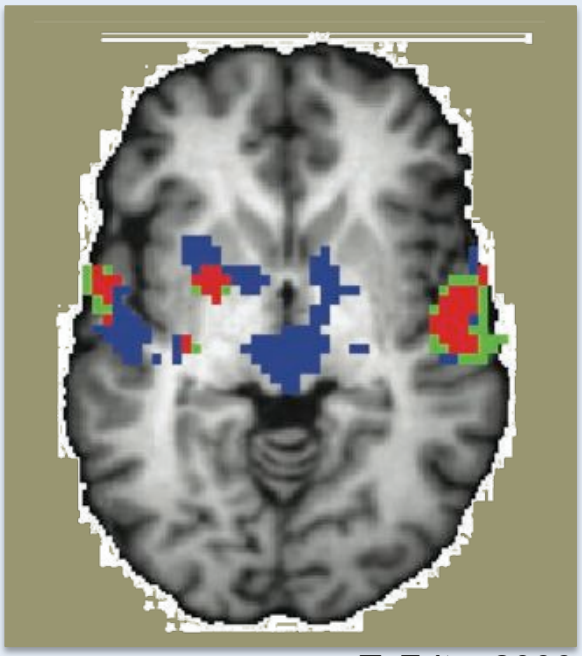


Onton & Makeig, *Frontiers in Human Neuroscience* '09

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



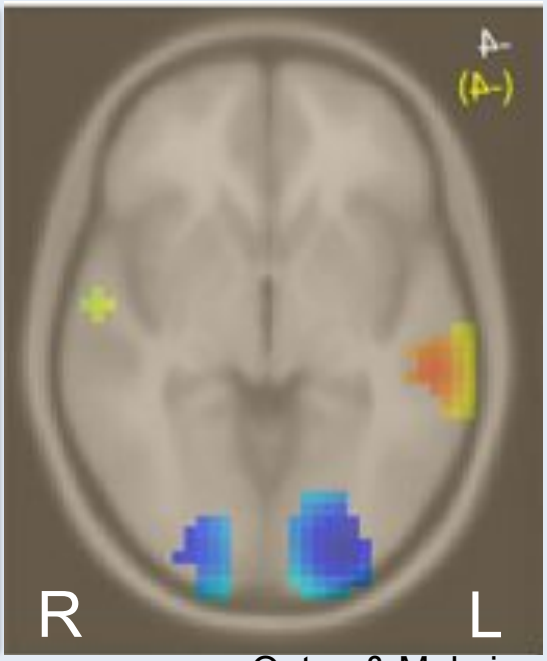
Julie Onton & Scott Makeig, *Frontiers in Human Neuroscience*, 2009



T. Fritz, 2009

fMRI

BOLD

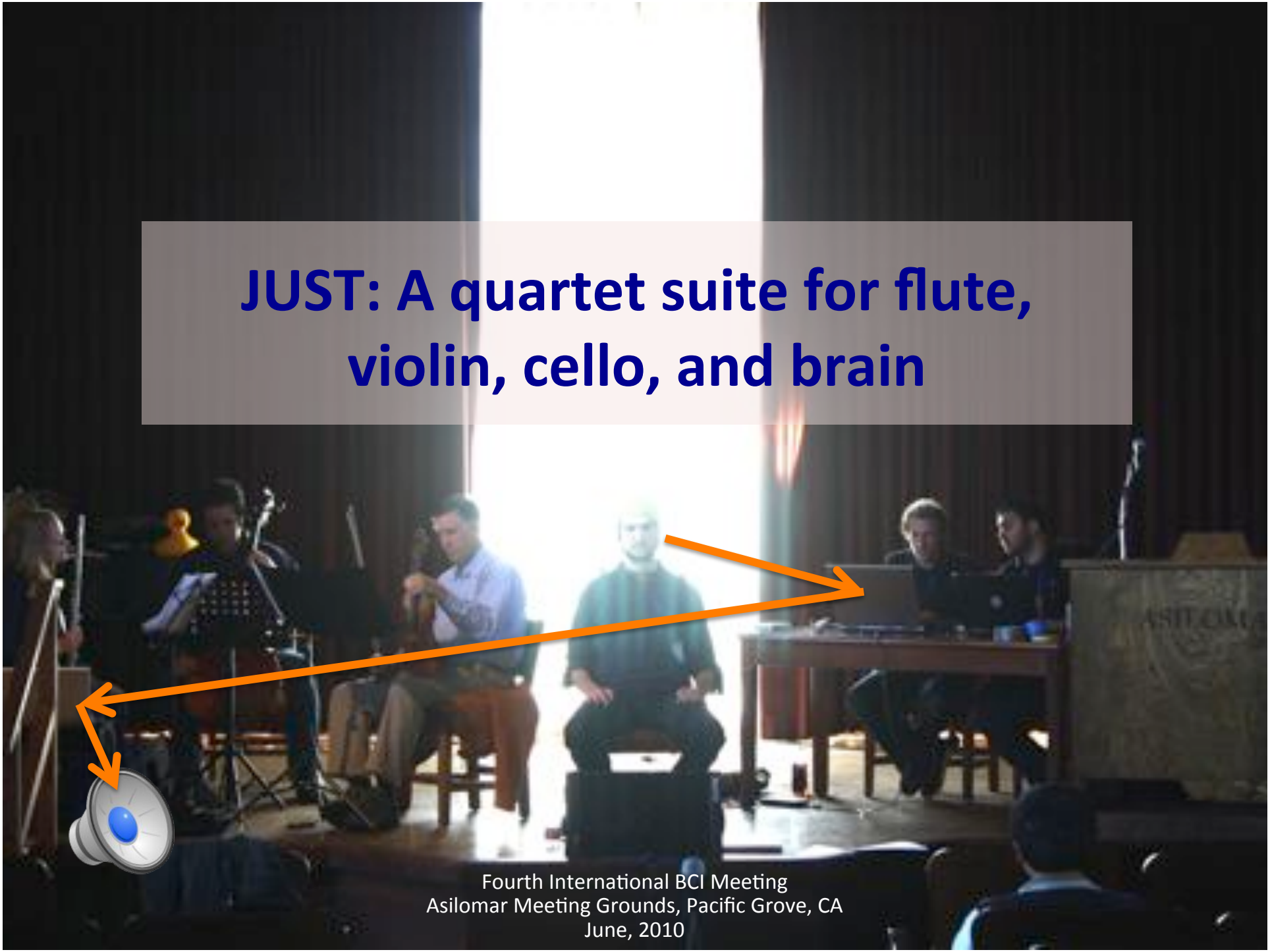


Onton & Makeig, 2009

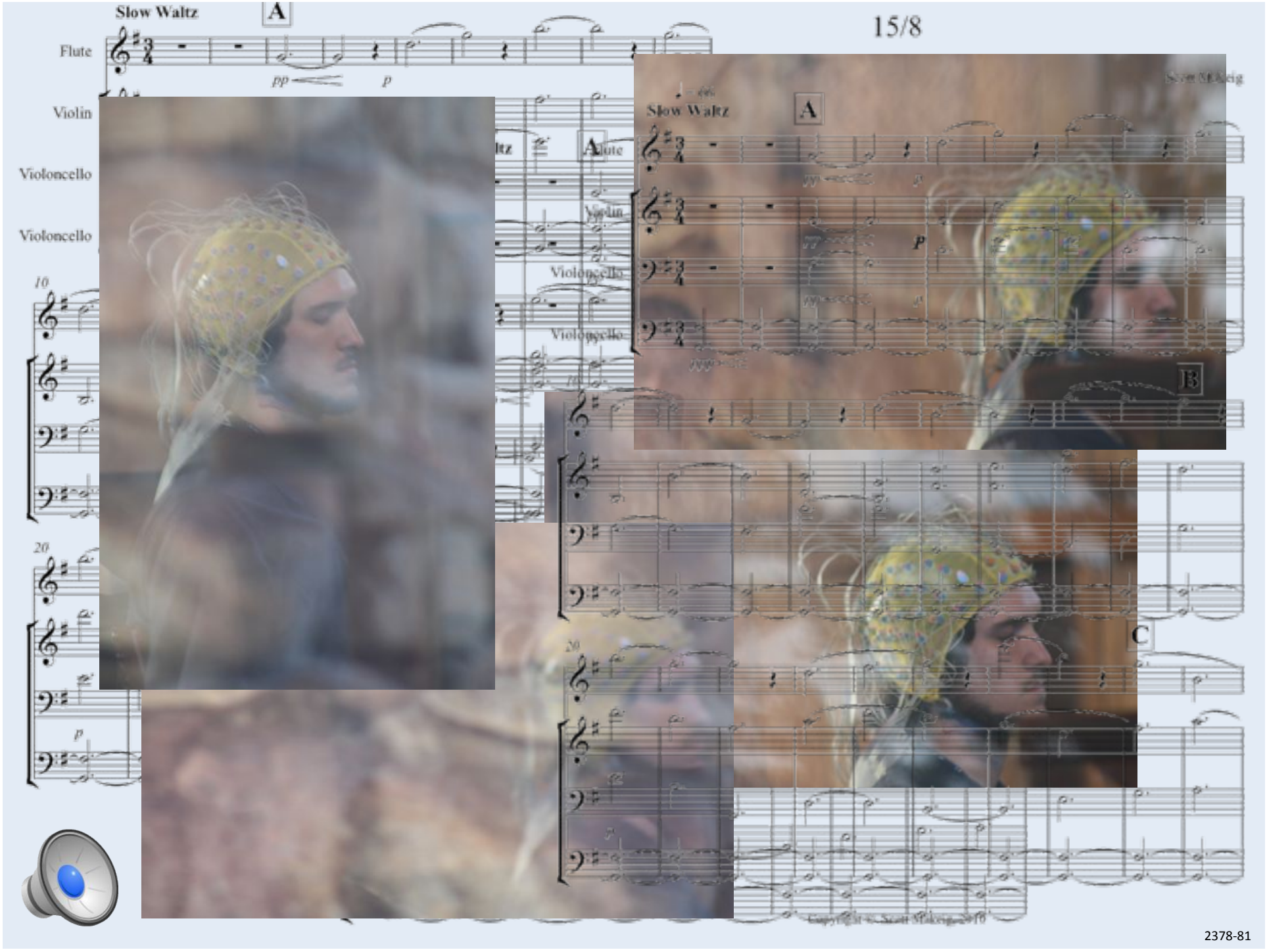
EEG

HFB

JUST: A quartet suite for flute, violin, cello, and brain



Fourth International BCI Meeting
Asilomar Meeting Grounds, Pacific Grove, CA
June, 2010


Slow Waltz
A
15/8
Flute
Violin
Violoncello
Violoncello
pp
p
Slow Waltz
A
B
C
p
2378-81

Q: How can I, as a musical composer & performer, communicate *affectively* to listeners?

What elements of music can I employ for this?

- Melody
- Harmony
- Rhythm
- Articulation
- Timbre
- Gesture

S Makeig, 2013

Rhythmic Principles

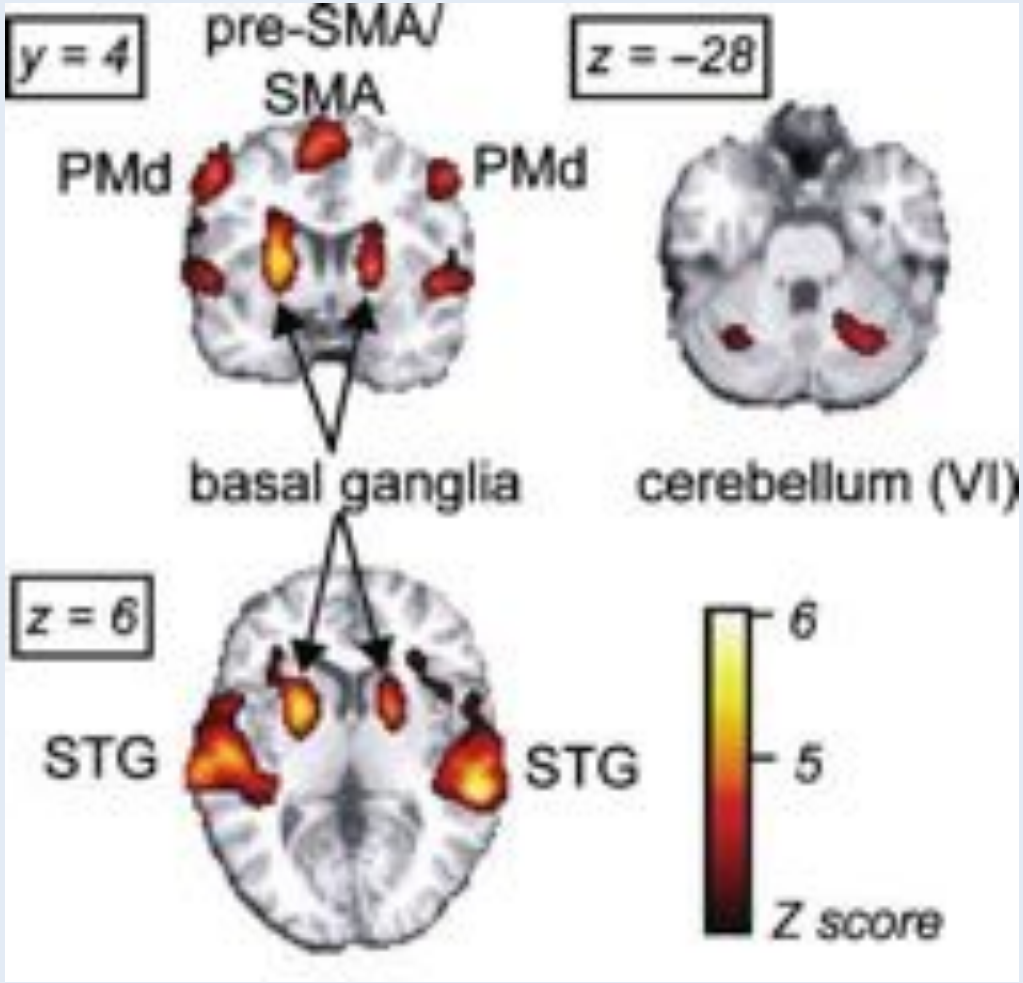
Sense

- Sense of Beat
- Sense of Pulse
- Sense of Accent
- Sense of Tempo
- Sense of Repetition
- Sense of Novelty
- Sense of Hierarchy

Activity

- Walking, running?
- Breathing, gesturing?
- Gesturing, jumping?
- Walking, running?
- Walking, swaying?
- Evasive movements?
- Dancing?

Beat-based rhythm perception or imagination activates motor areas even in absence of overt movements

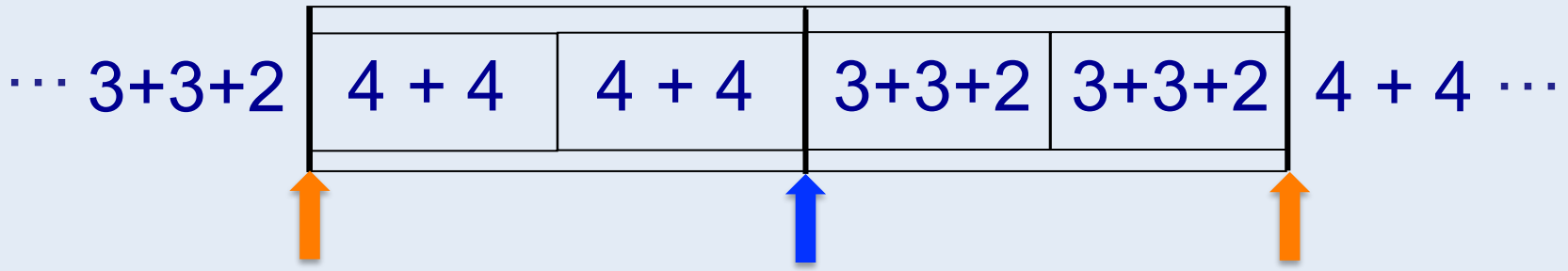


Grahn JA, Brett M (2007) *J Cogn Neurosci,*
Also Teki S, et al. (2011) *J Neurosci,*
Fujikoa, et al. (2012) *J Neurosci.*

John Iversen, 2014

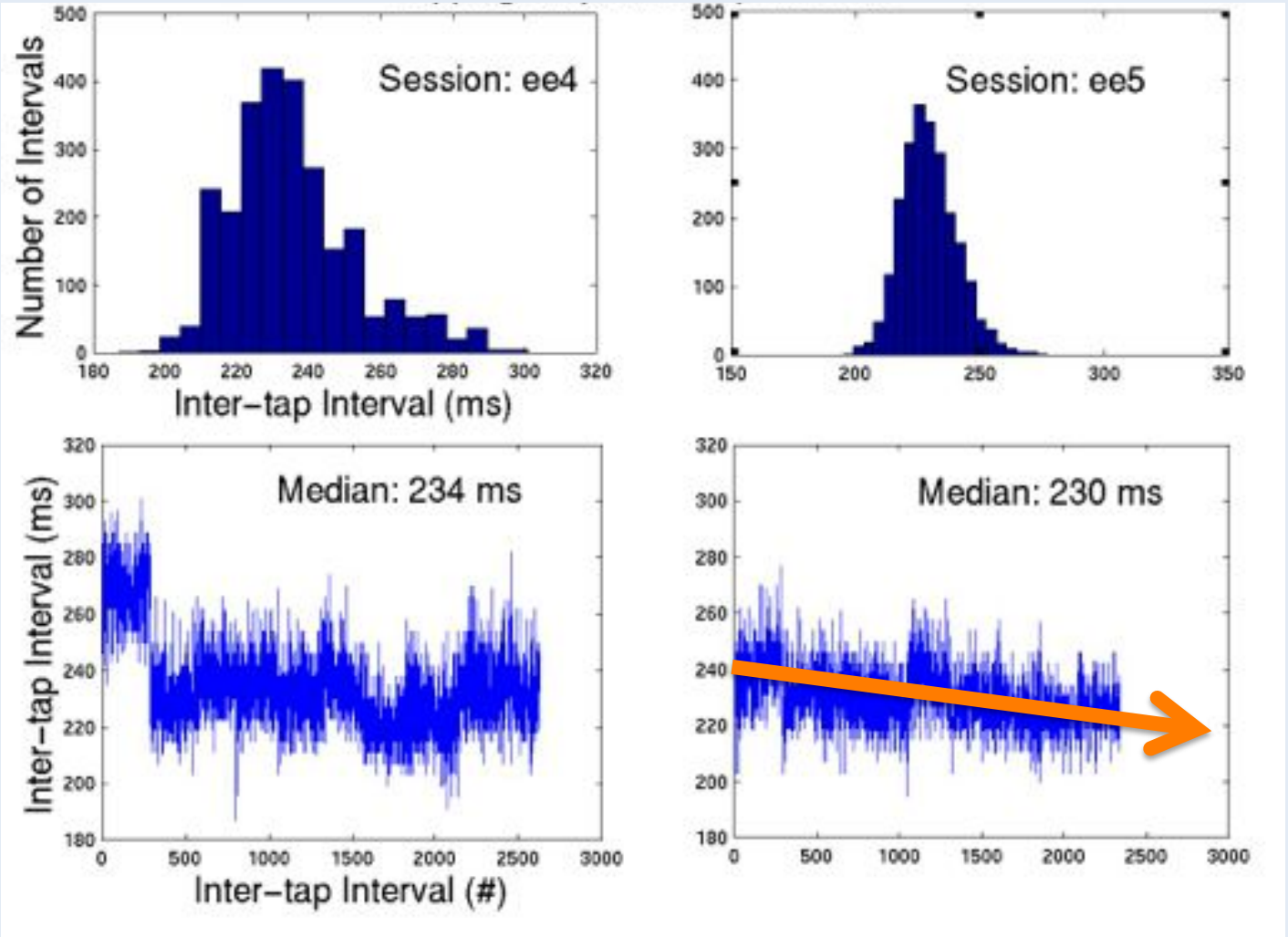
A 'Tapping Music' Performance Experiment

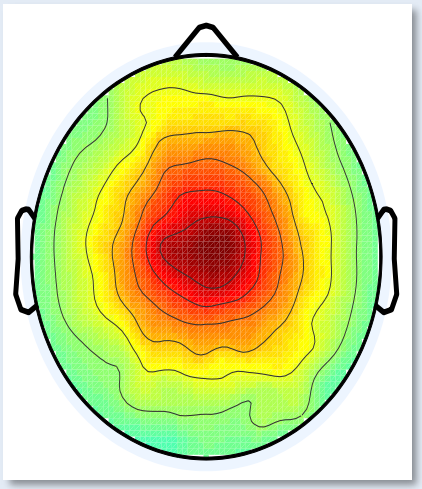
- **Click-paced or self-paced rhythmic tapping**
- Performance of a "piece" of music involving
  - A regular rhythmic pulse (isochronous)
  - Two musical meters
  - Regular switching back and forth between meters



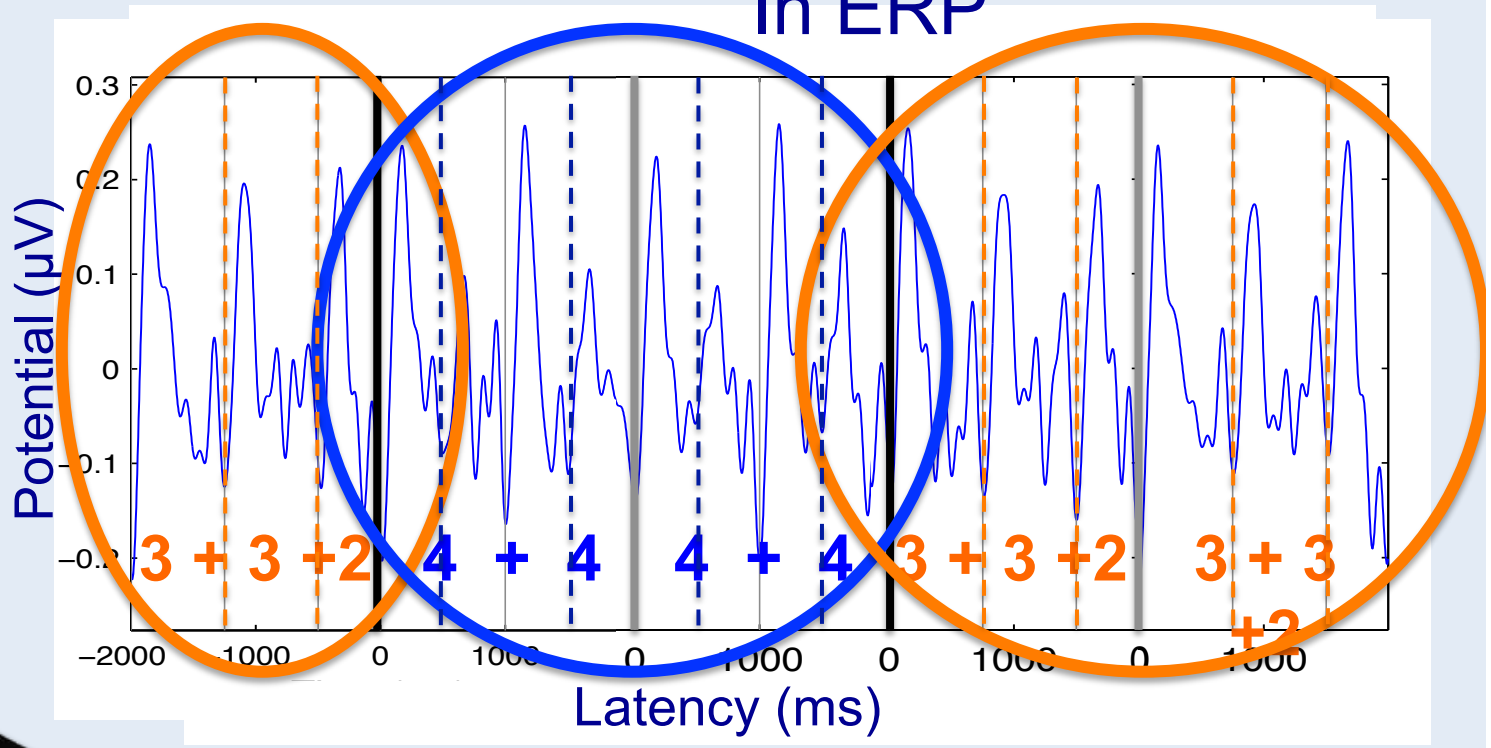
Metric Modulation

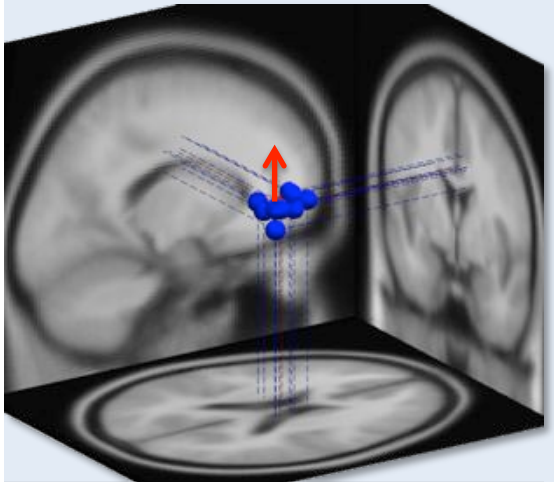
Solo Performance
(no click track)



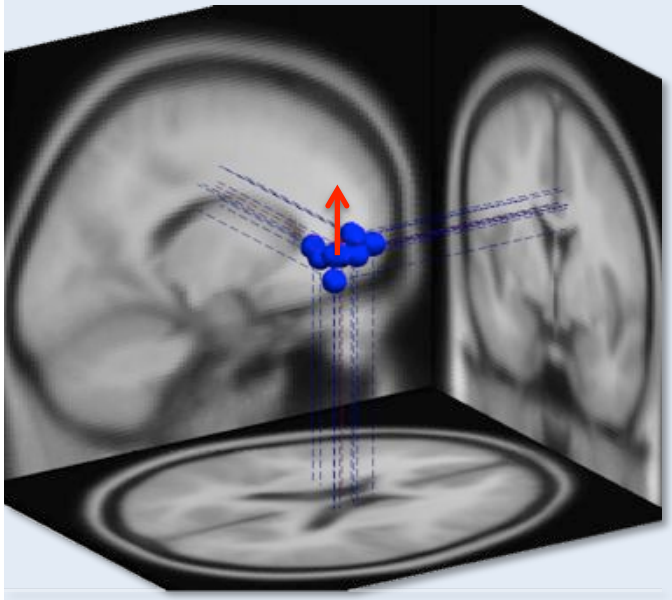


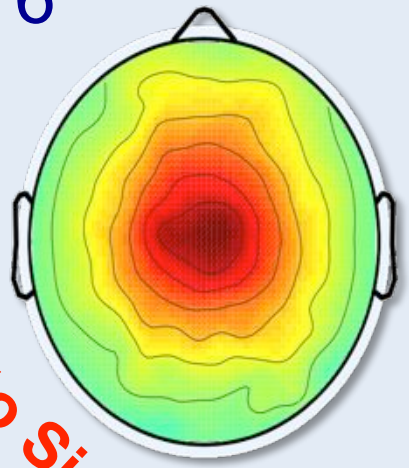
IC Source Cluster 6
Beat Following
In ERP





IC Source Cluster 6
Beat Following
at 25 Hz & 6 Hz





Cls 6 ERSP, 144

Frequency (Hz)

44 37 31 28 26 24 21 19 17 15 13 11 9 7 5

−1000 0 1000

Time (ms)

Cls 6 ERSP, 244

−1000 0

Time (ms)

Cls 6 ERSP, 133

−1000 0 1000

Time (ms)

Cls 6 ERSP, 233

−1000 0 1000

Time (ms)

Cls 6 ERSP, 144

−1000 0 1000

Time (ms)

dB

1.3 0.7 0 −0.7 −1.3

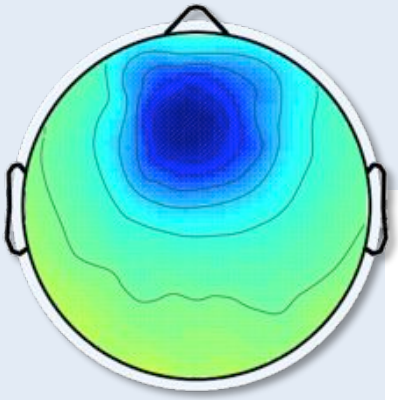
Down Beats

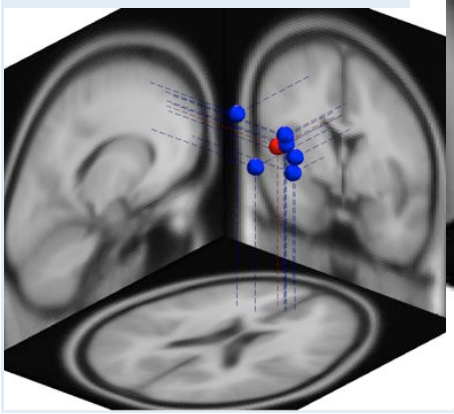
But No Sign of Metric Modulation

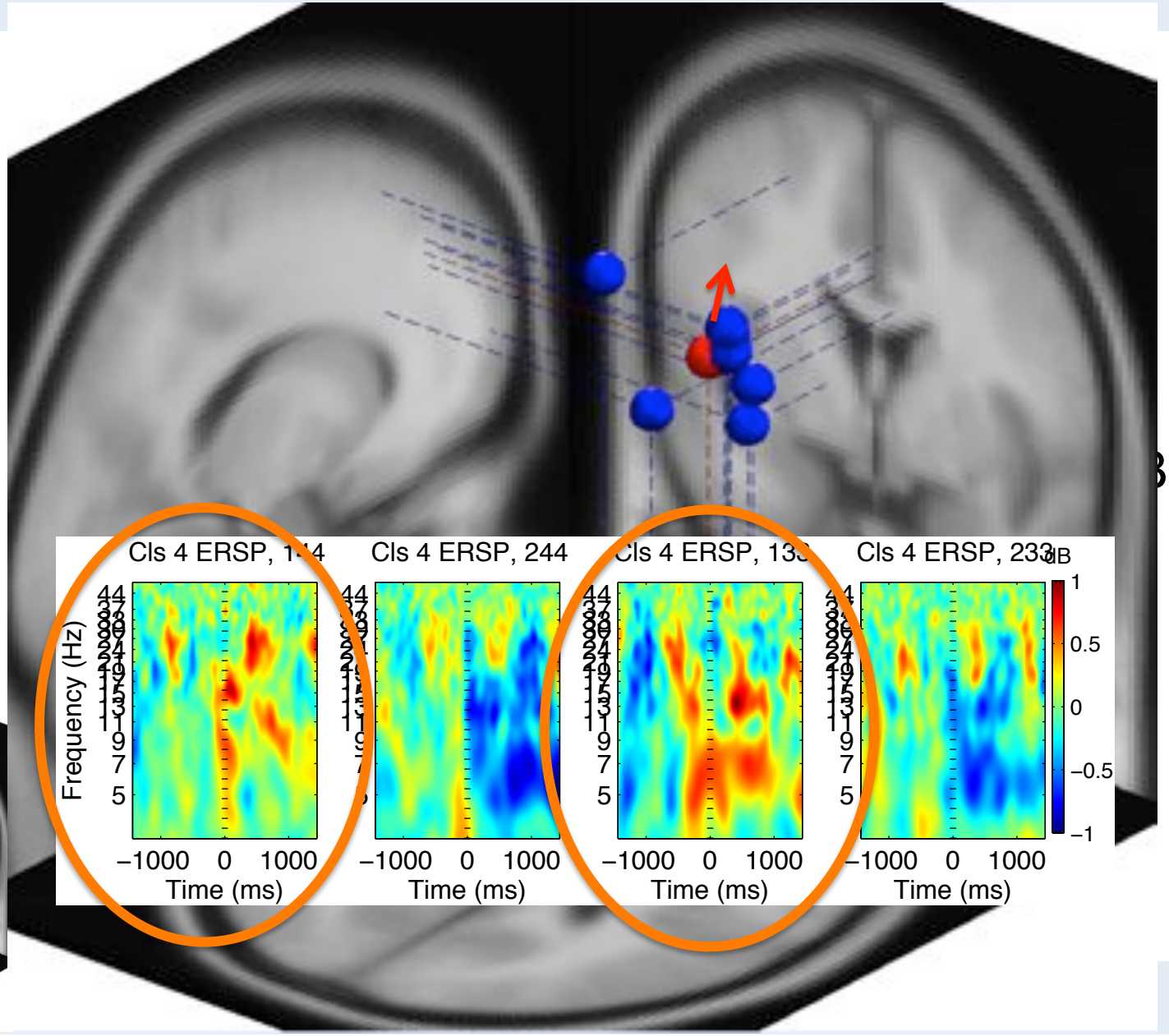
3 + 3 + 2 Barlines

IC Source Cluster 4

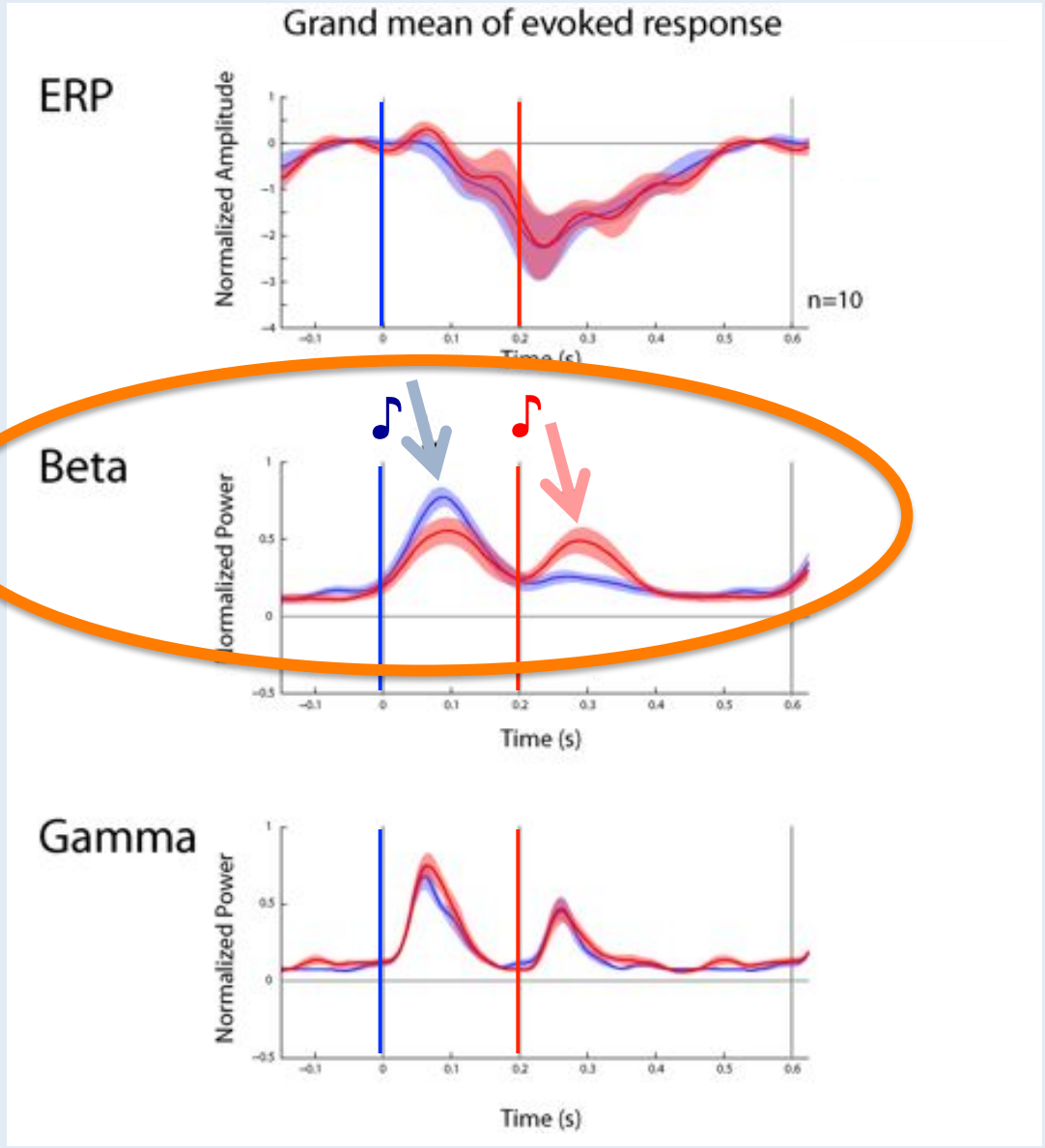
Metric Modulation ≠ Metric Repeat

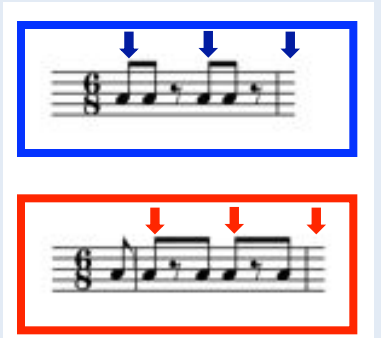






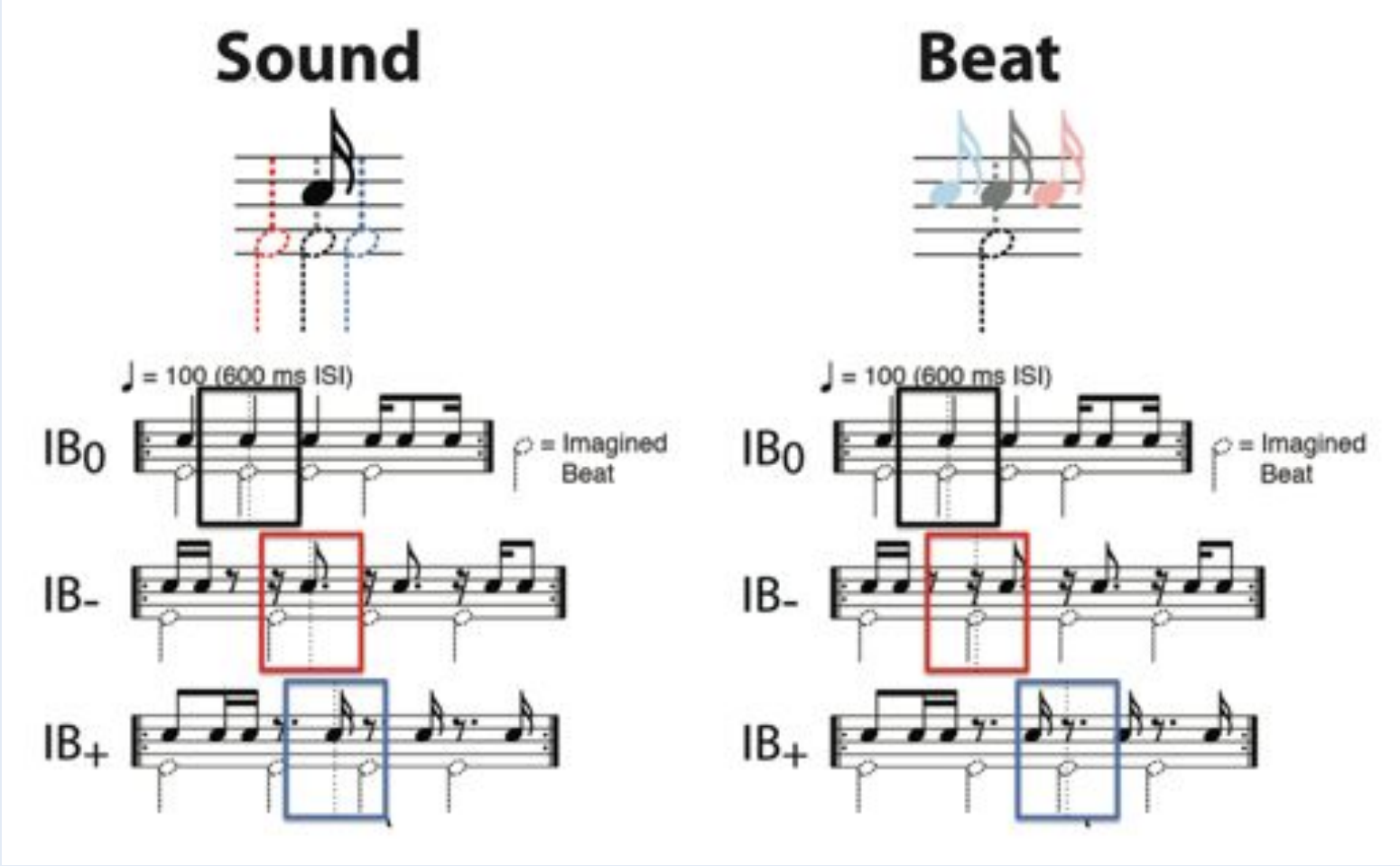
MEG beta band activity increases following tones perceived as carrying the beat





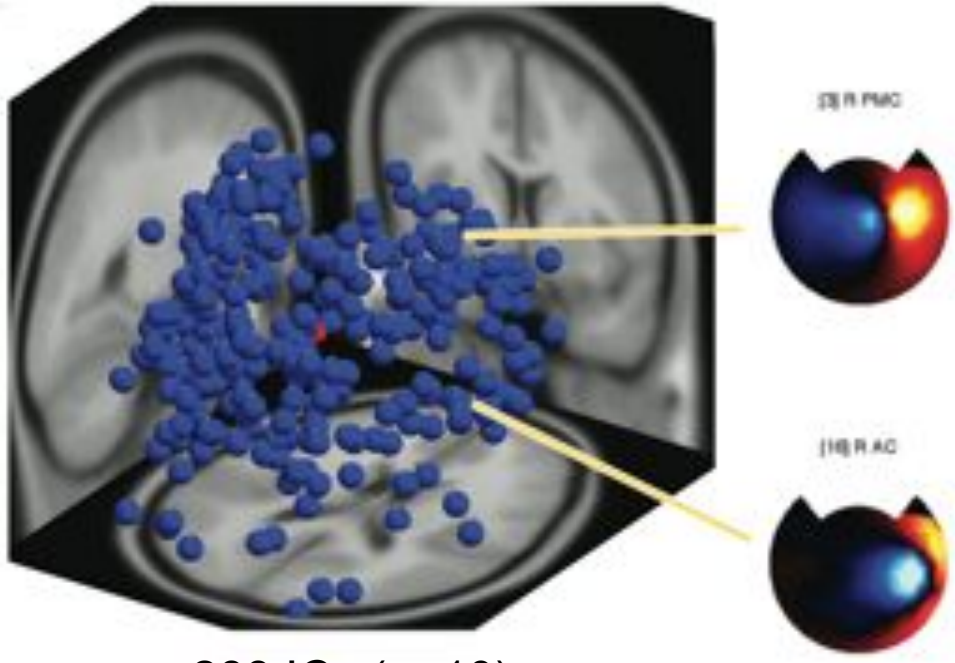
Iversen, Patel & Repp, 2009

Three percepts, same data:
Time-locking to the sound vs. to the internal beat

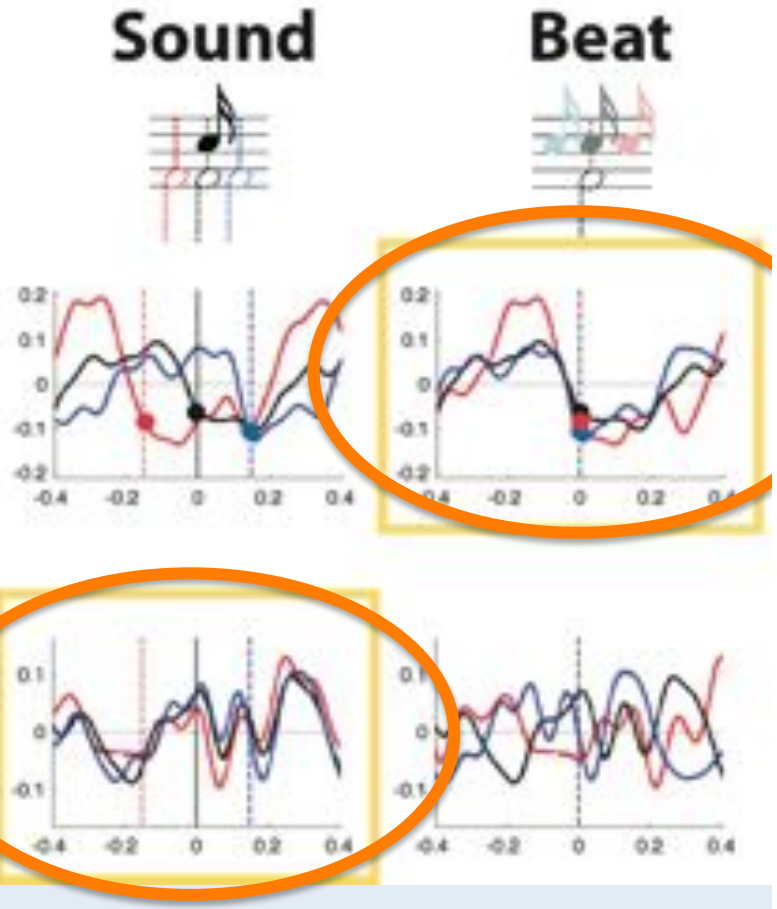


John Iversen, 2014

Independent Component ERF Classification

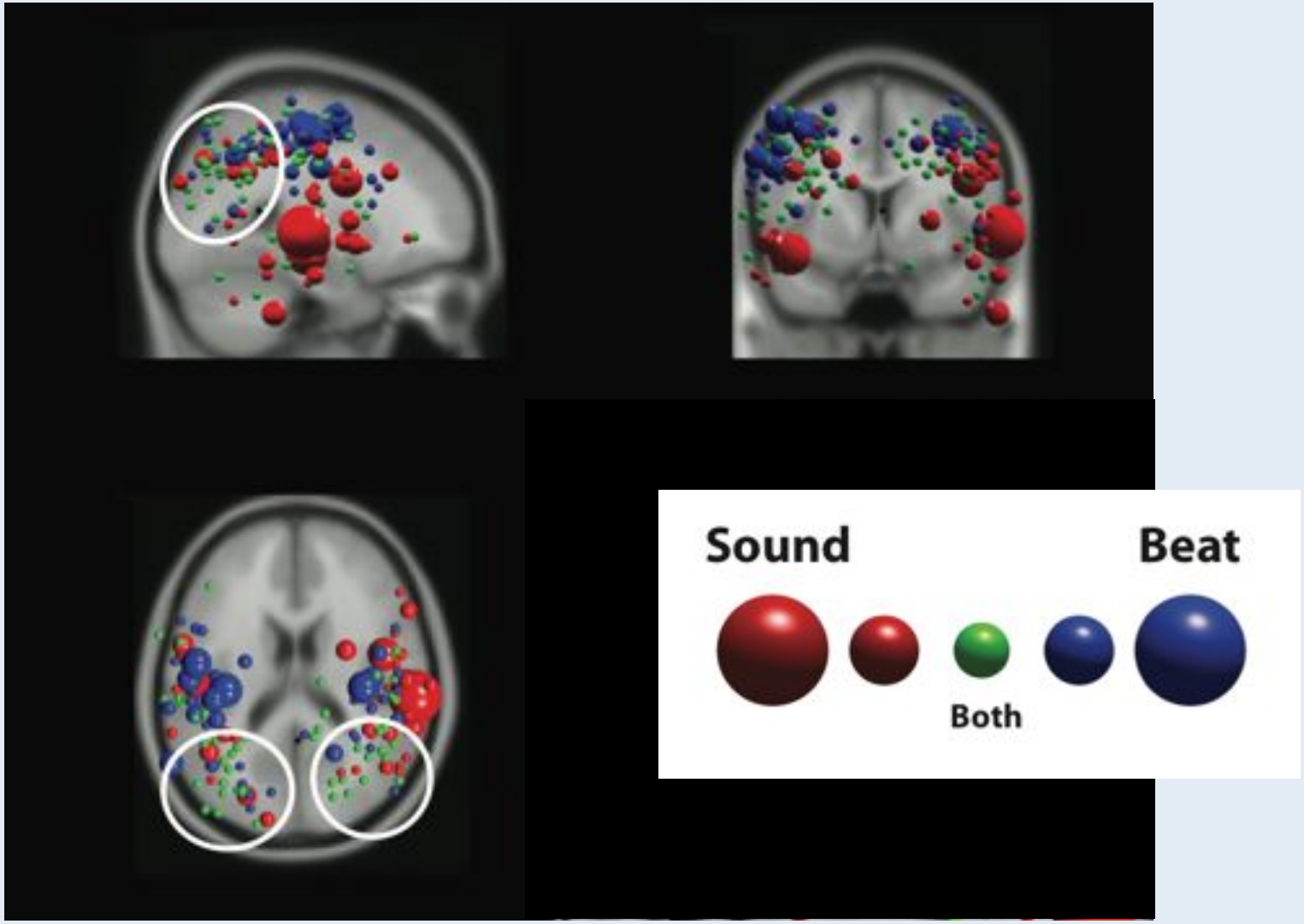


288 ICs (n=10)

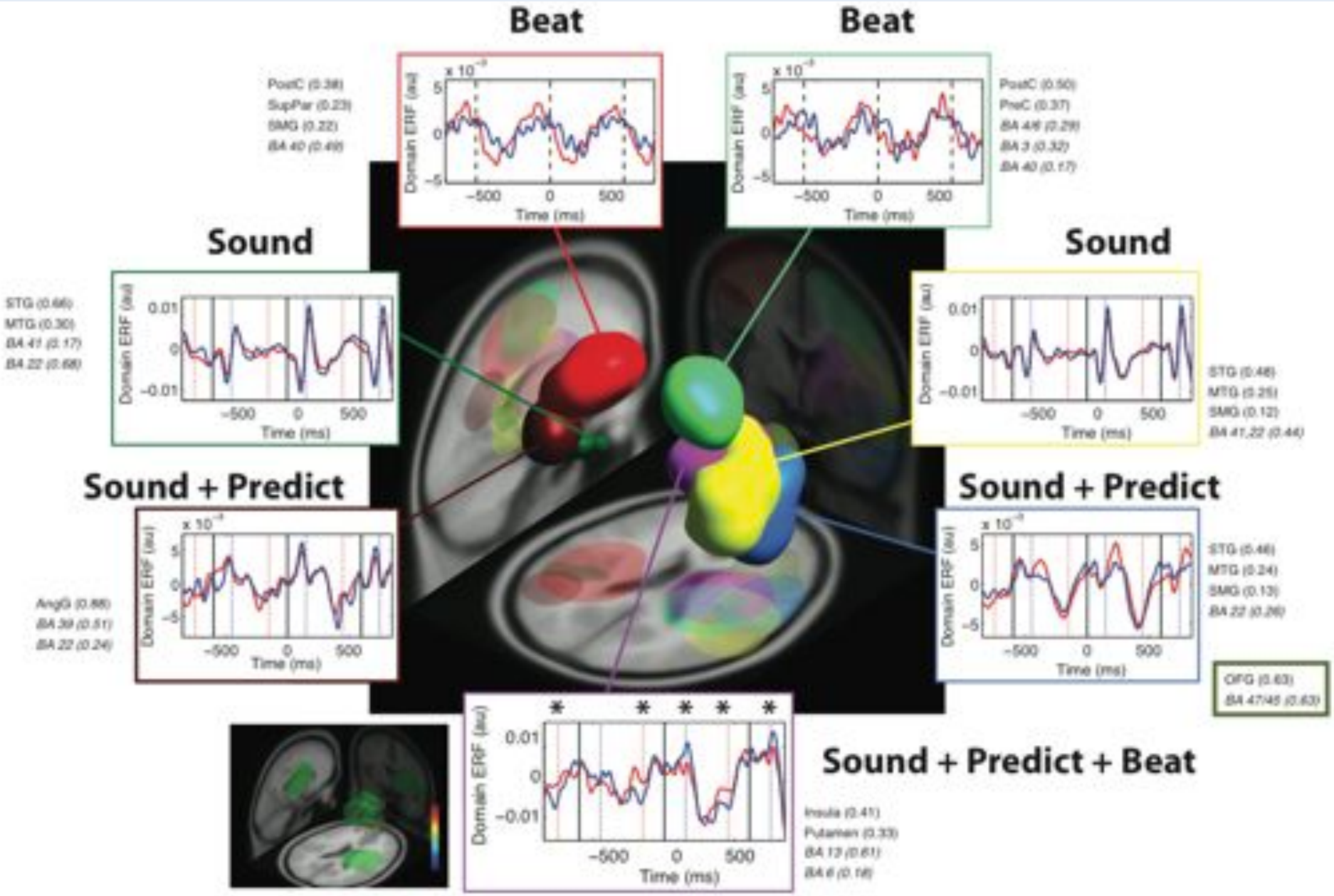


John Iversen, 2014

Sound-locked vs. Beat-locked ICs



John Iversen, 2014


Beat
Beat
PostC (0.38)
SupPar (0.23)
SMG (0.22)
BA 40 (0.49)
PostC (0.50)
PreC (0.37)
BA 4/6 (0.29)
BA 3 (0.32)
BA 40 (0.17)
Sound
Sound
STG (0.66)
MTG (0.30)
BA 41 (0.17)
BA 22 (0.68)
STG (0.46)
MTG (0.25)
SMG (0.12)
BA 41,22 (0.44)
Sound + Predict
Sound + Predict
AngG (0.68)
BA 39 (0.51)
BA 22 (0.24)
STG (0.46)
MTG (0.24)
SMG (0.13)
BA 22 (0.26)
OFG (0.63)
BA 47/45 (0.63)
Sound + Predict + Beat
Insula (0.41)
Putamen (0.33)
BA 13 (0.61)
BA 6 (0.16)
Domain ERF (au)
Time (ms)

Q: How can I, as a musical composer & performer, communicate *affectively* to listeners?

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- Articulation
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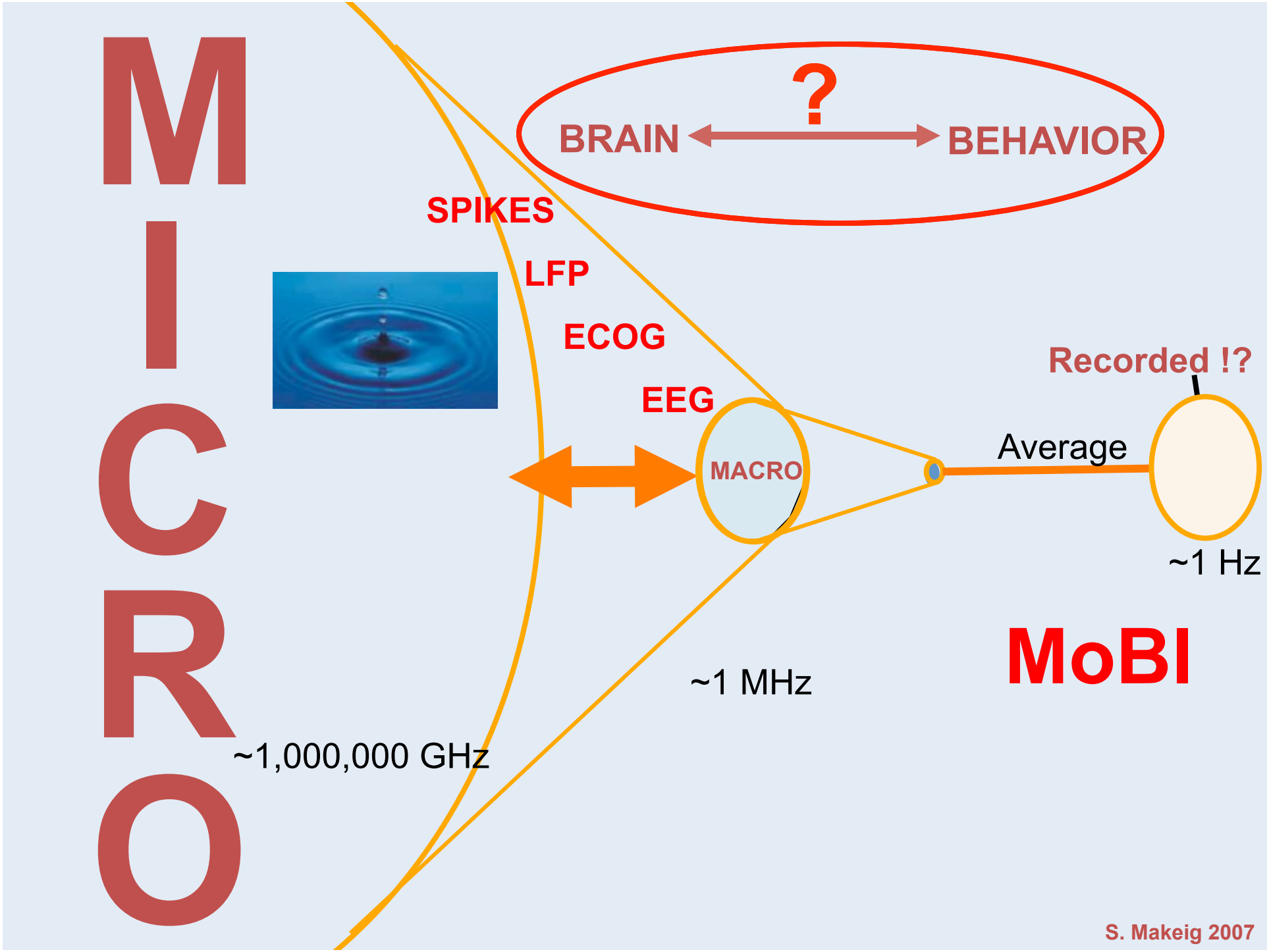
- Gesture

S Makeig, 2013


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

Brain imaging during motor behavior?

- Nearly all brain imaging studies (MEG, PET, fMRI, and EEG) are conducted in rigidly stationary seated or prone positions with only the most minimal finger movements allowed.

Why?

- In all modalities but EEG sensors are **heavy**.
- Muscle and movements contribute ('noise') signals.

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

has never been observed or modeled!

Scott Makeig 2008

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

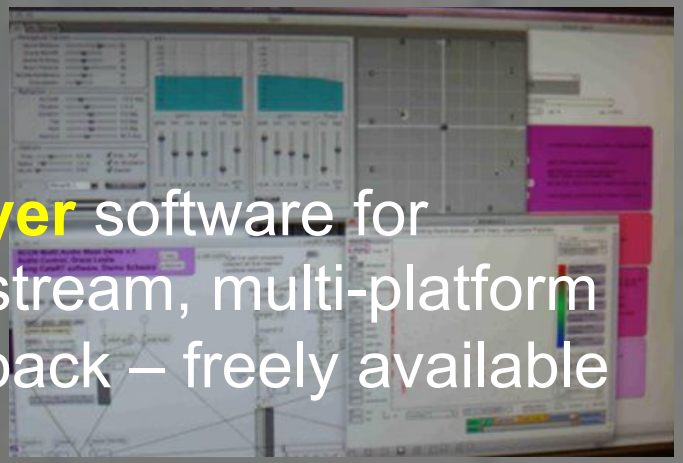
to find, model, and measure

non-stationary (context- and intention-related)

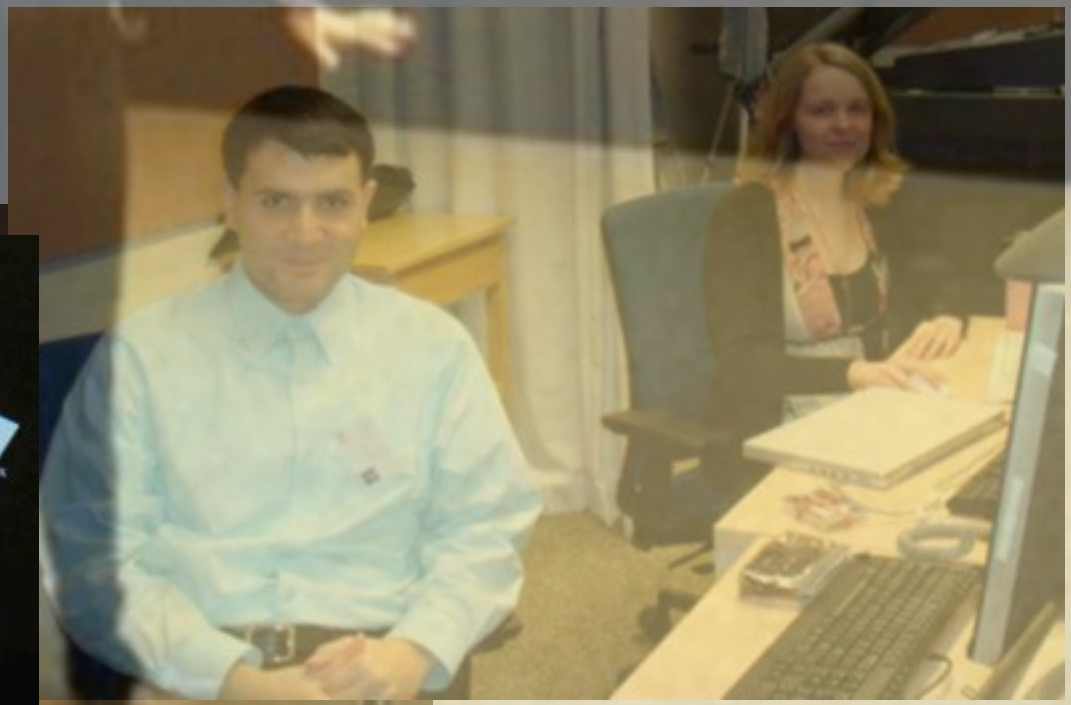
functional relationships among these data modalities.

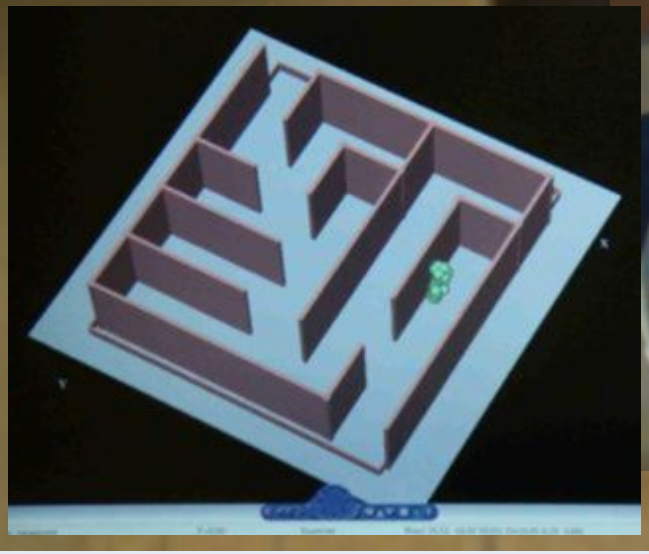
Scott Makeig, 2011

MoBI Lab at SCCN, UCSD



Lab Streaming Layer software for synchronous multi-stream, multi-platform recording and feedback – freely available on Google Code.





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

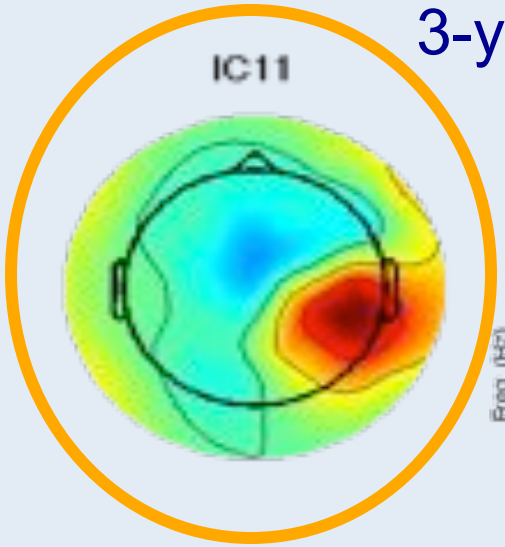
S Makeig & M Miyakoshi, 20112

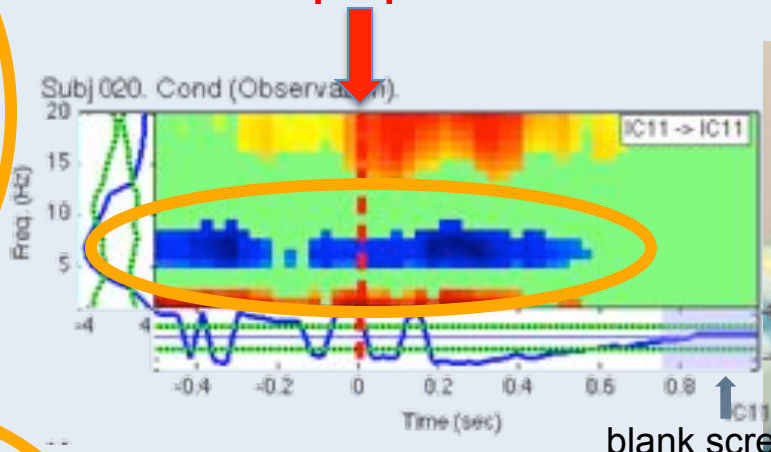
Development of Shared Attention – A Mother and Child MoBI Experiment

Gedeon Deak et al., 2011

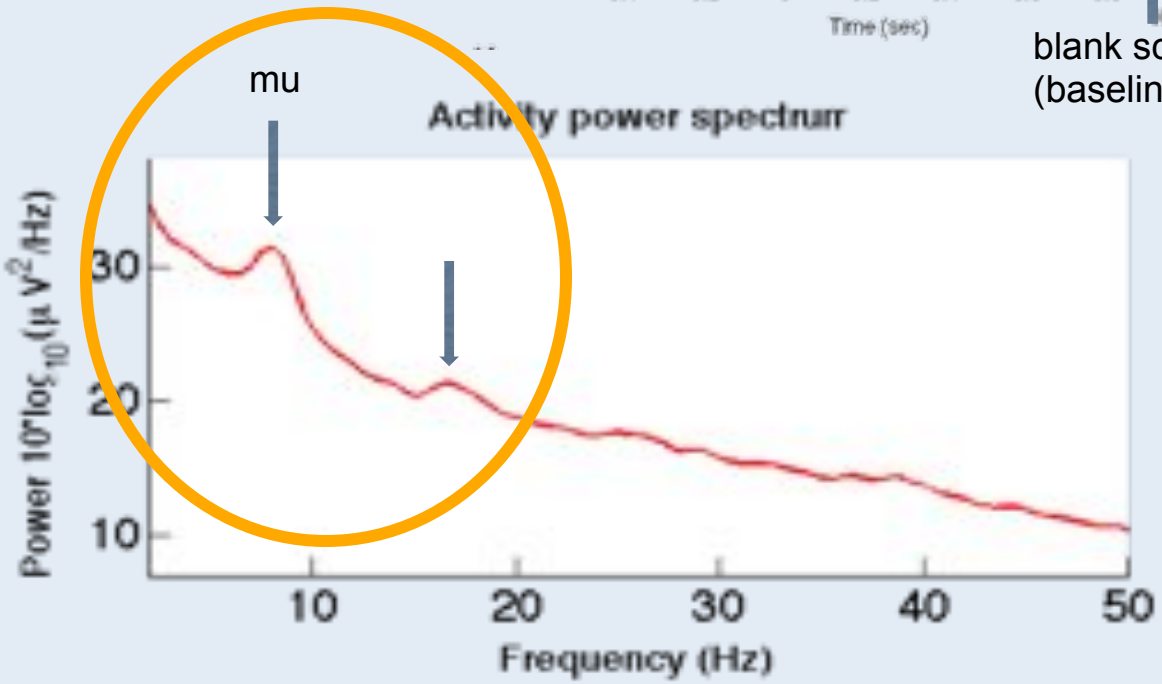
3-yr old child's brain – Reward Observation

Mother pops the bubble!





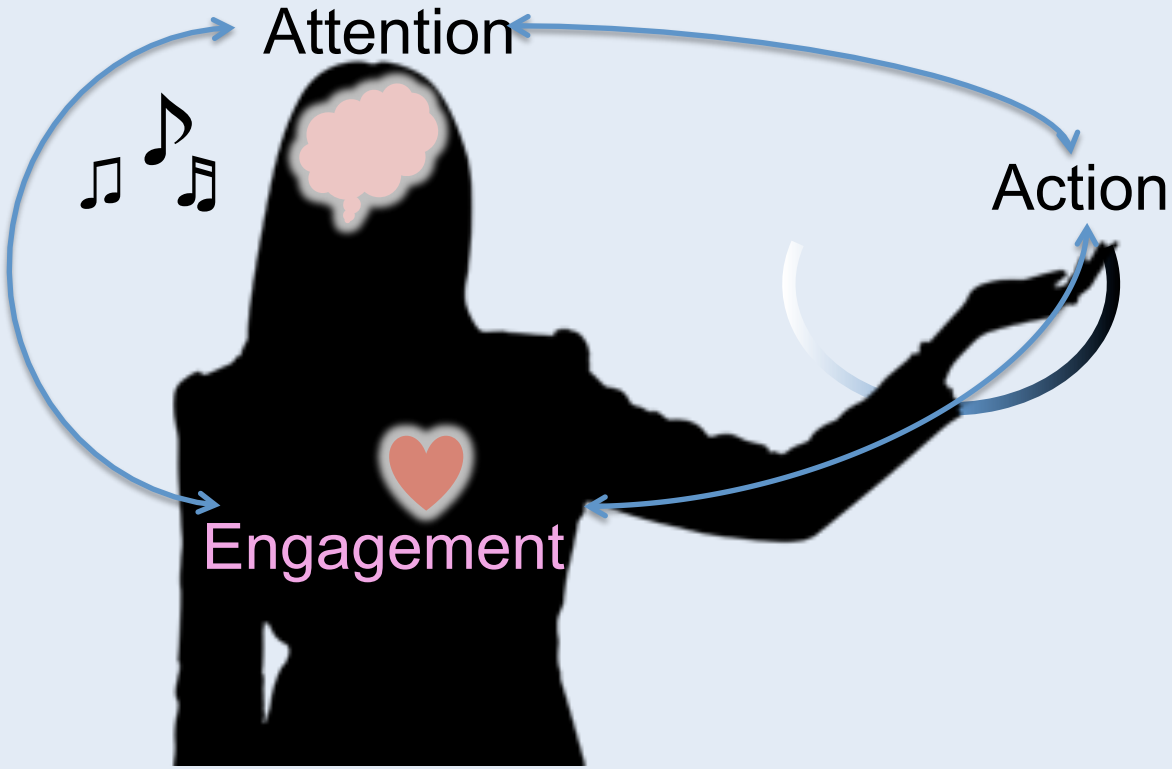
blank screen
(baseline)



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

Measuring Musical Engagement Through Expressive Rhythm

How can we measure a listener's engagement level?



G Leslie & S Makeig,

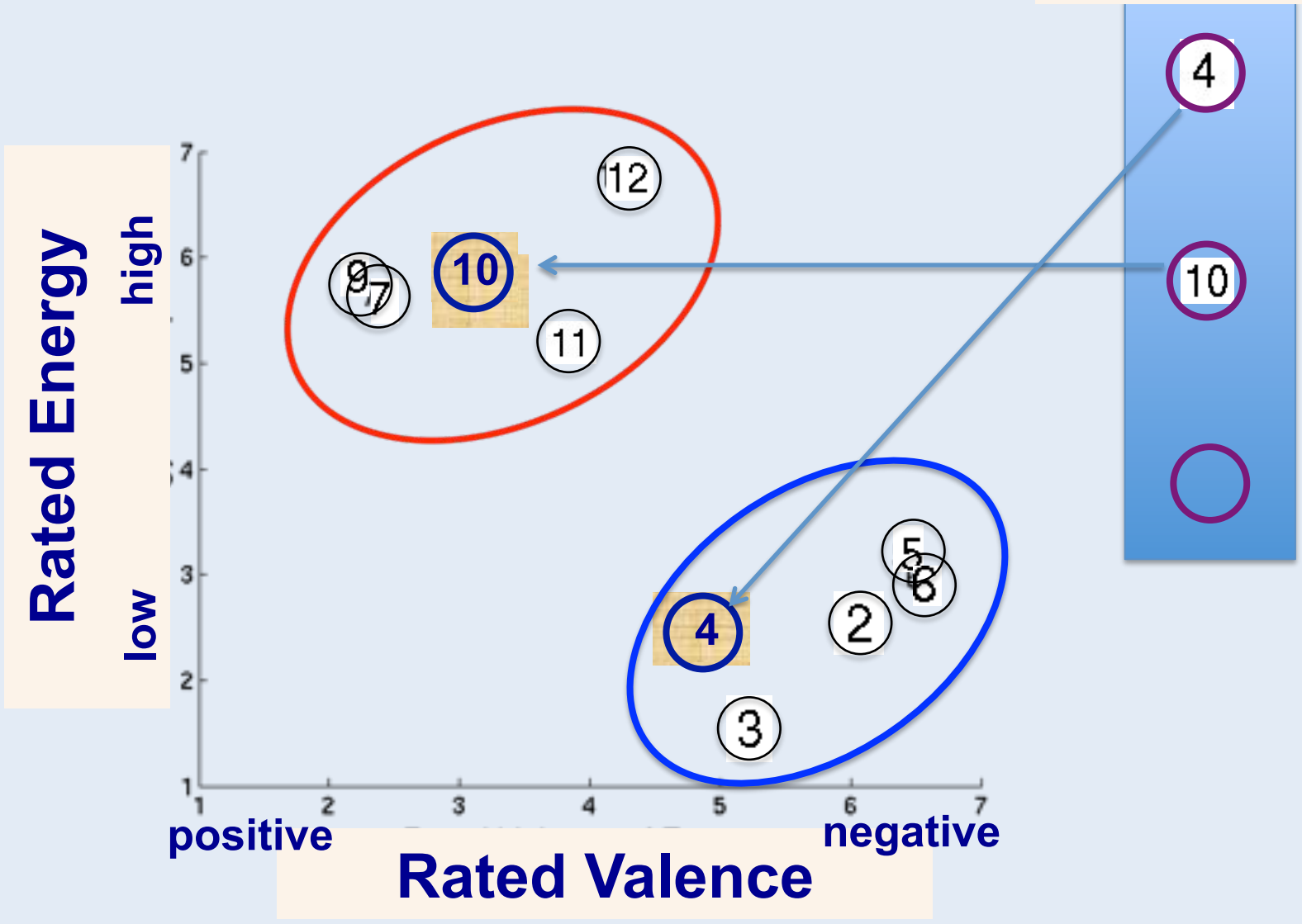
Rhythmic expression task

The Heart is a Lonely Hunter (1968)

The Conducting Experiment

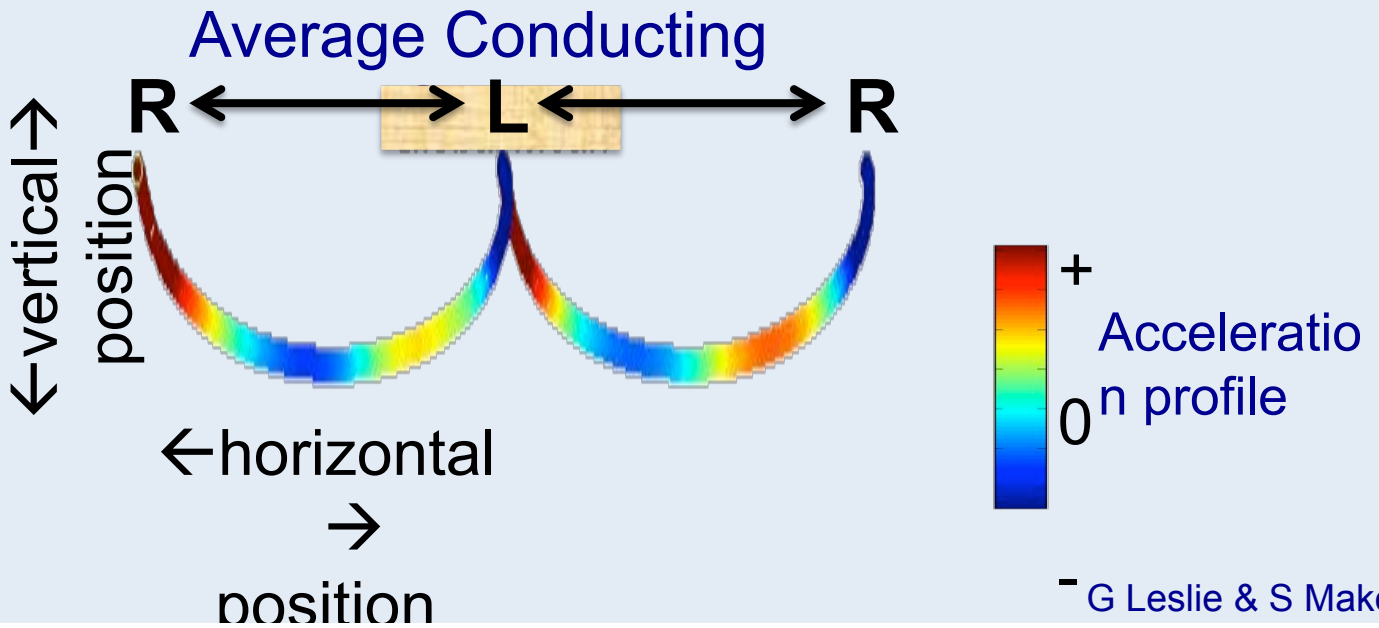
G Leslie & S Makeig,

10 Musical Excerpts



G Leslie & S Makeig,

Live translation of the conducting gesture to moving dot



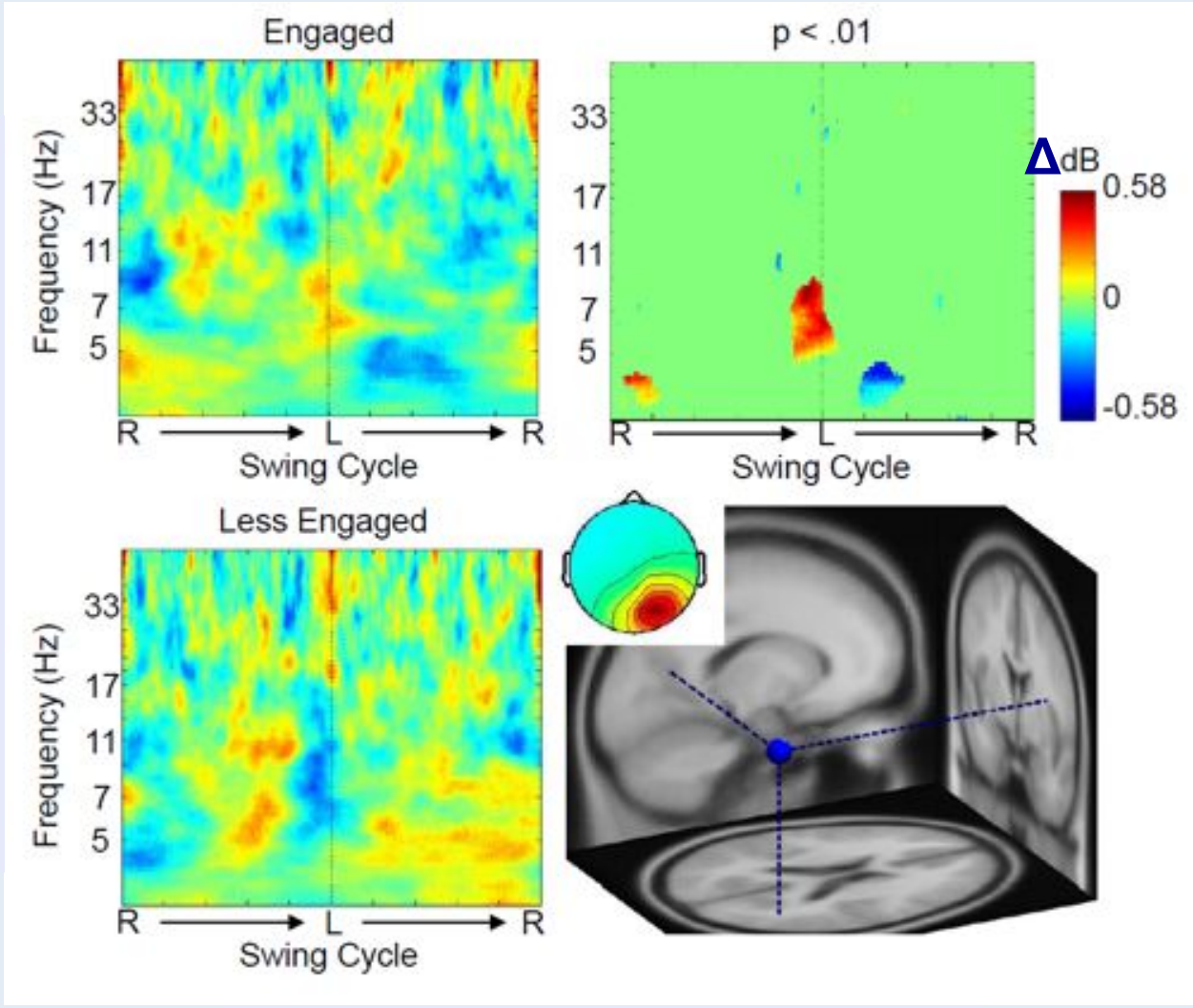
- G Leslie & S Makeig,

Survey respondents by Internet location

Moving spot animations

G Leslie & S Makeig,

EEG Result



Frequency (H)

Swing Cycle

Scott Makeig, 2014