Auditory Neuroscience with Magnetoencephalography: New Quantitative Approaches

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APAN 2010

Outline

- *Auditory Magnetoencephalography*
  - *MEG Fundamentals*
  - *Neural Source Localization*
- *"Newish" Quantitative Approaches*
- *MEG in the Fourier Domain*
- *Signal Separation & Denoising*

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Origin of MEG Neural Signal

Dendritic currents

not

Axonal currents

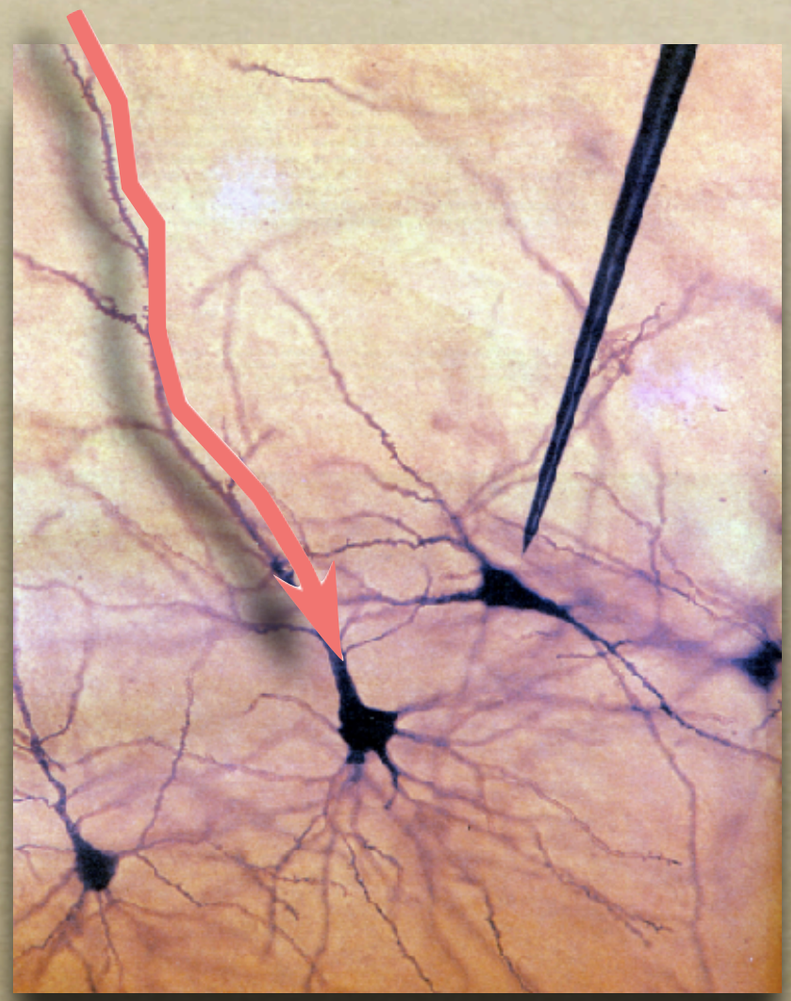
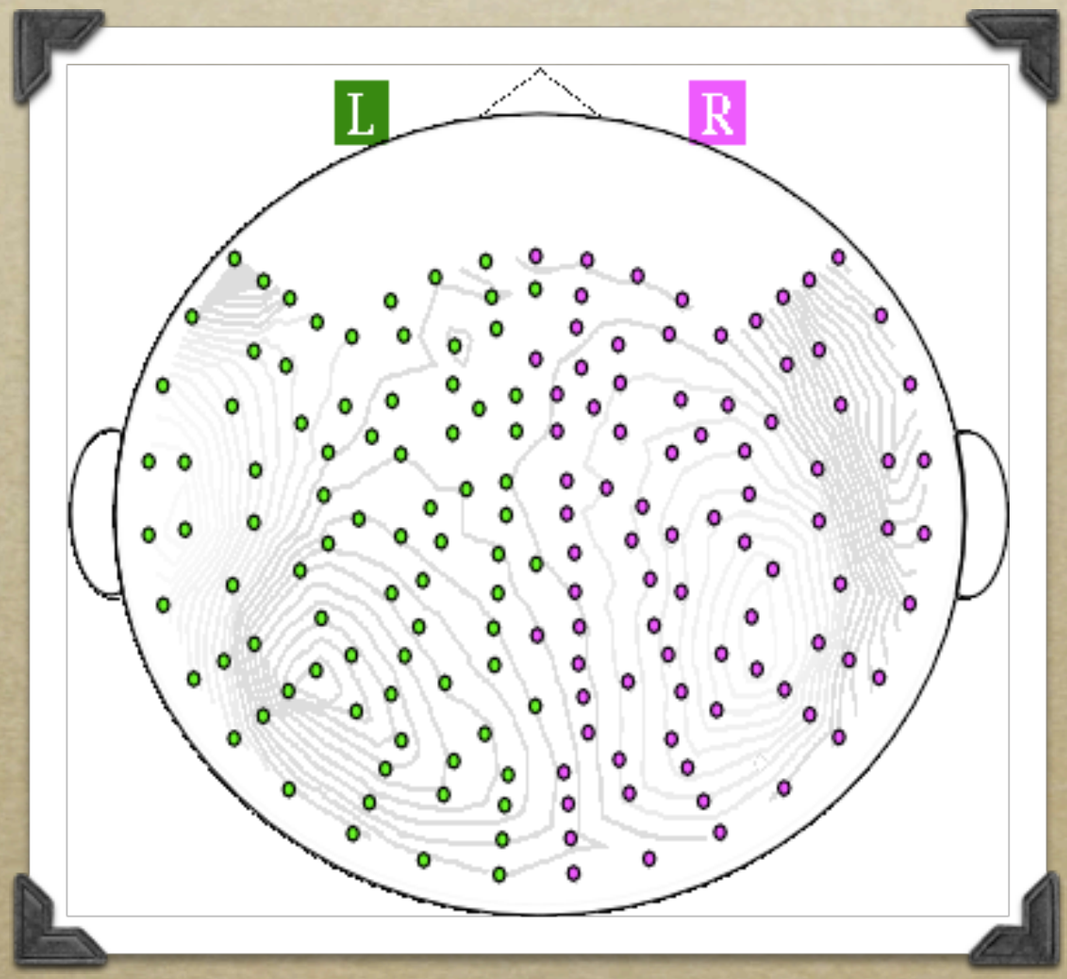


Photo by Fritz Goro

Magnetoencephalography

- *Non-invasive, Passive, Silent Neural Recordings*
- *Simultaneous Whole-Head Recording (~200 sensors)*
- *Sensitivity*
  - *high: ~100 fT (10^{-13} Tesla)*
  - *low: ~10^4 – ~10^6 neurons*
- *Temporal Resolution: ~1 ms*
- *Spatial Resolution*
  - *coarse: ~1 cm*
  - *ambiguous*



Functional Brain Imaging

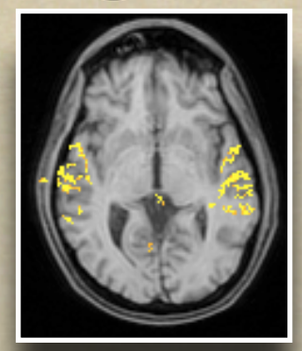
Functional Brain Imaging
= Non-invasive recording from human brain

Hemodynamic techniques

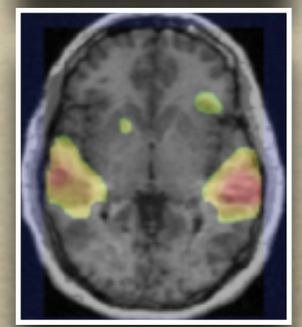
Excellent Spatial Resolution ***(~1 mm)***

Poor Temporal Resolution ***(~1 s)***

fMRI
functional magnetic resonance imaging



PET
positron emission tomography

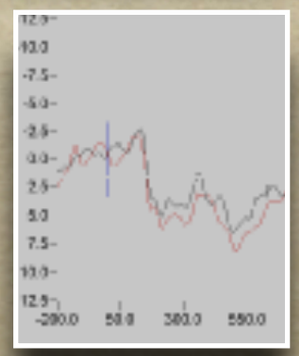


fMRI & MEG can capture effects in single subjects

Electromagnetic techniques

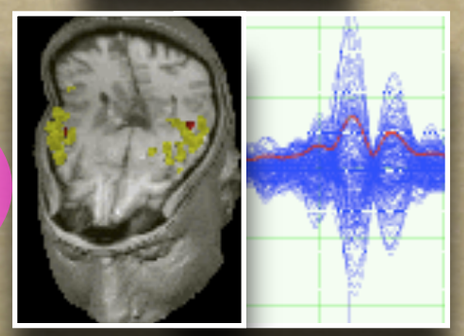
Poor Spatial Resolution ***(~1 cm)***

EEG
electroencephalography

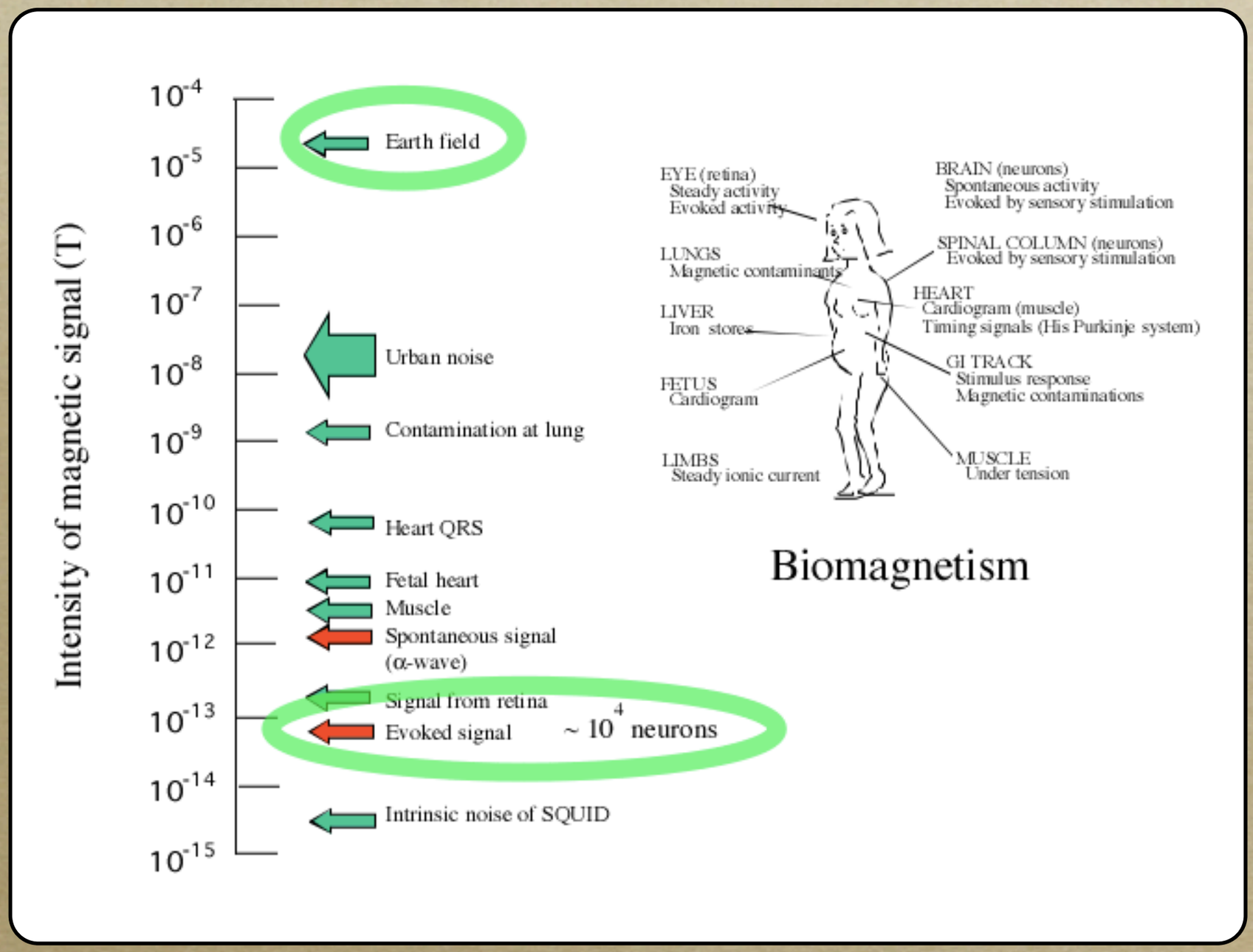


Excellent Temporal Resolution ***(~1 ms)***

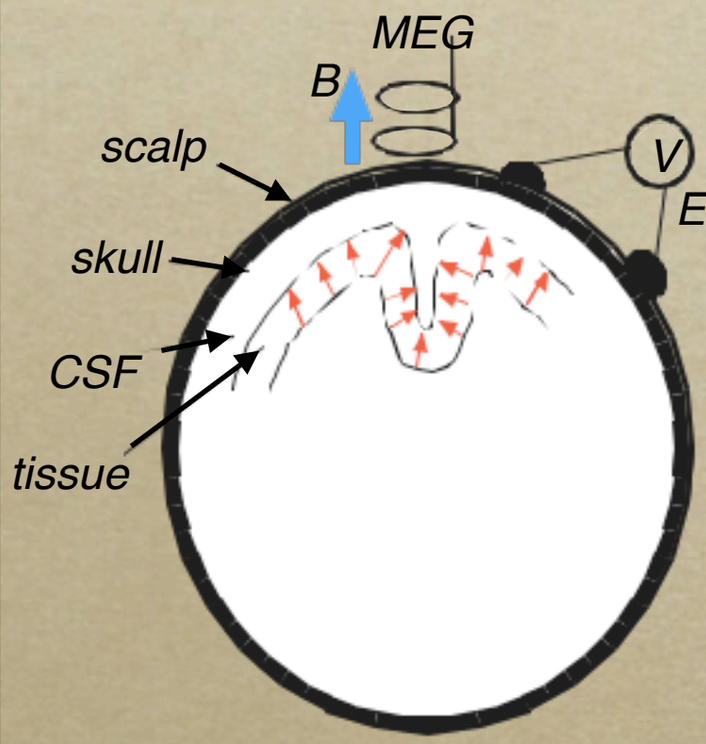
MEG
magnetoencephalography

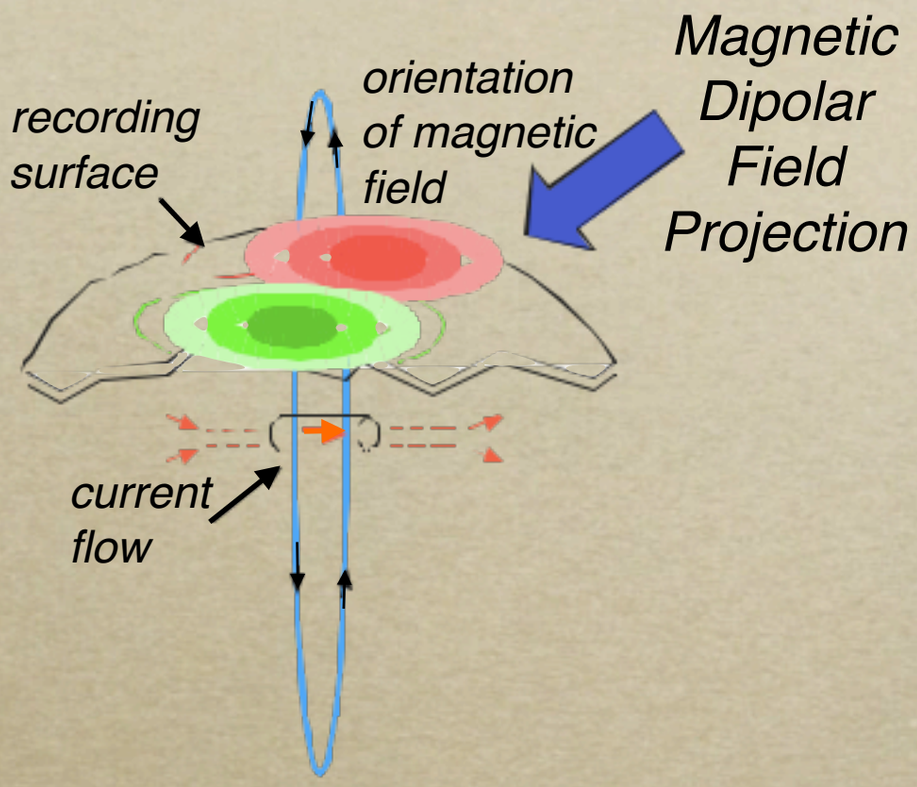


Magnetic Field Strengths



MEG Magnetic Signal

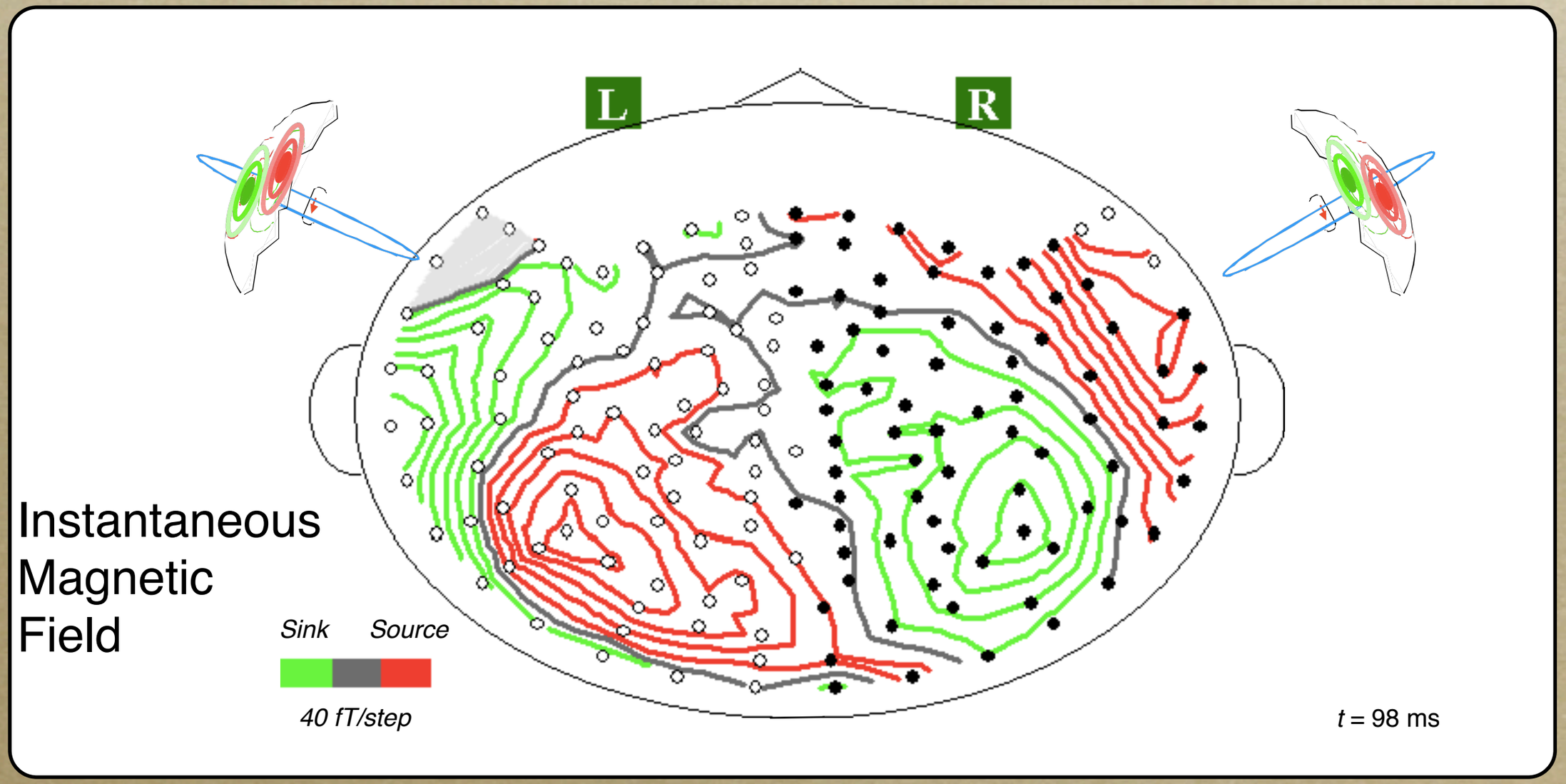




- *Direct electrophysiological measurement*
  - *not hemodynamic*
  - *real-time*
- *No unique solution for distributed source*

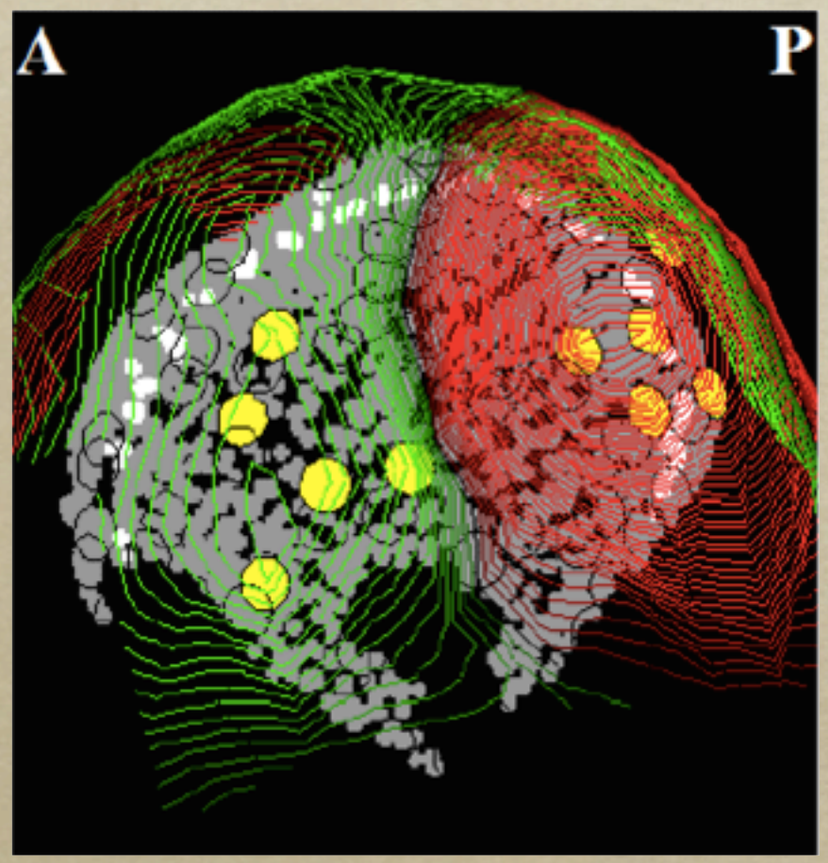
MEG Auditory Field

Flattened Isofield Contour Map

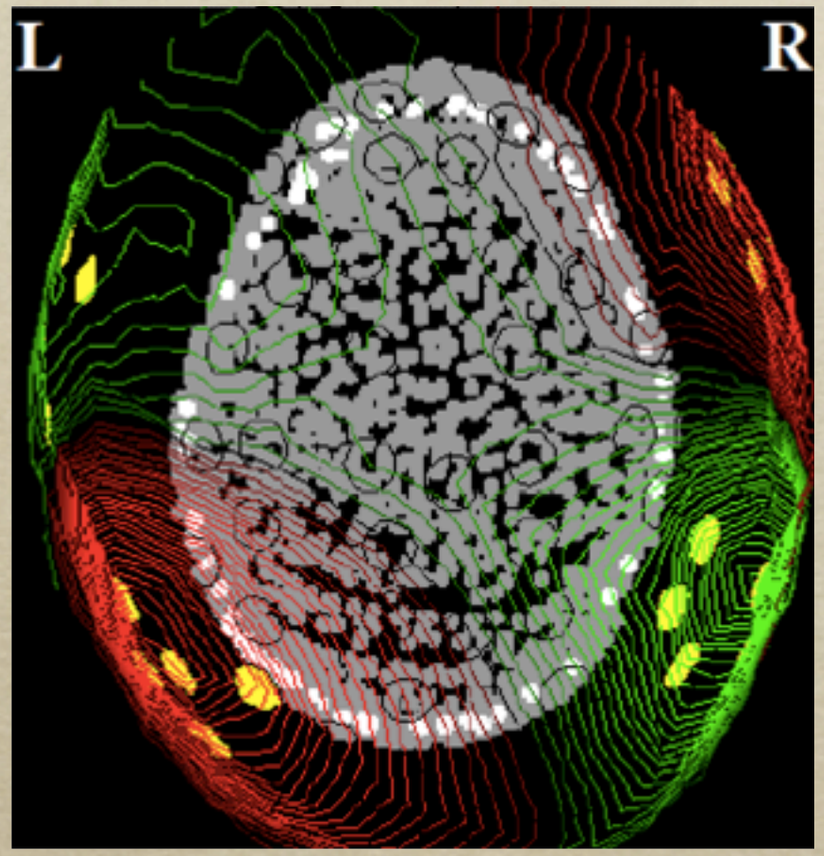


MEG Auditory Field

3-D Isofield Contour Map



Sagittal View

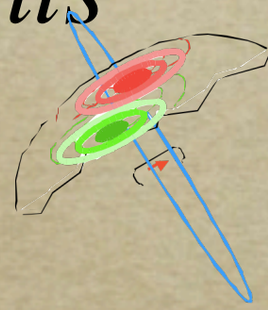


Axial View

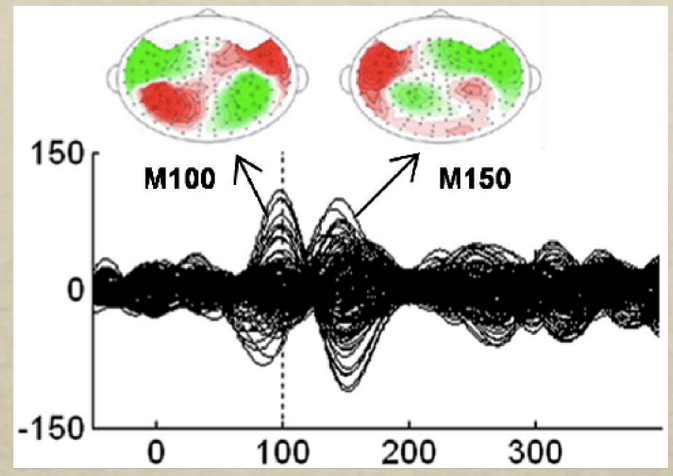
Chait, Poeppel and Simon, Cerebral Cortex (2006)

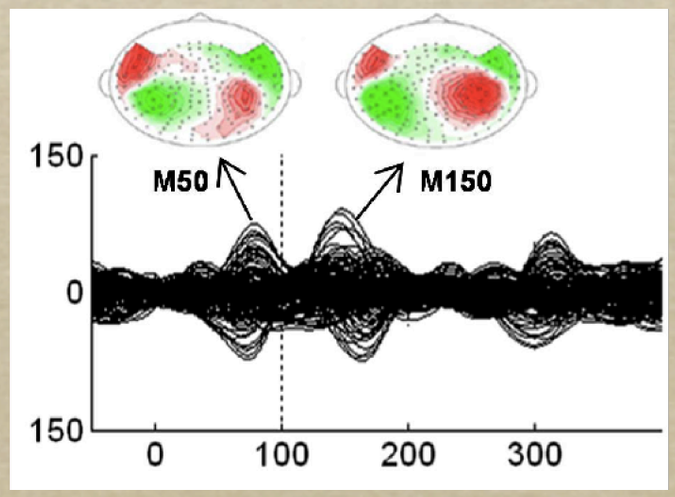
Time Course of MEG Responses

- ***Auditory Evoked Responses***
  - *MEG Response Patterns Time-Locked to Stimulus Events*
  - *Robust*
  - *Strongly Lateralized*



Pure Tone





Broadband Noise

- ***Auditory Induced Responses***
  - *MEG Response Patterns not Time-Locked to Stimulus Events*
  - *Not Addressed Today*

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Neural Source Localization

- *No Unique Solution from Magnetic Field to Neural Current Distribution ("Inverse Problem")*
- *Several Plausibly Phyisological Solutions*
  - *Equivalent-Current Dipoles*
  - *Minimum Norm Estimation & variants*
  - *Beamforming & variants*
  - *Others*

Neural Source Troubles

- *Equivalent-Current Dipoles*
  - *How Many?*
  - *Non-intuitive side effects*
- *Minimum Norm Estimation vs. Beamforming*
  - *Each side can produce datasets that show misleading results form other method*
- *Excellent Tutorial*
  - *Lütkenhöner & Mosher in "Auditory Evoked Potentials" by Burkard et al.*

Neural Source Solutions?

- *All of the major methods are good*
  - *Can give physiologically plausible result*
  - *Can give "correct/true" result*
- *Any of the major methods might get you into trouble*
  - *Each has weaknesses*
- *The best method to use may be the one which is used by people whose results you trust*
  - *Knowing an expert always helps*

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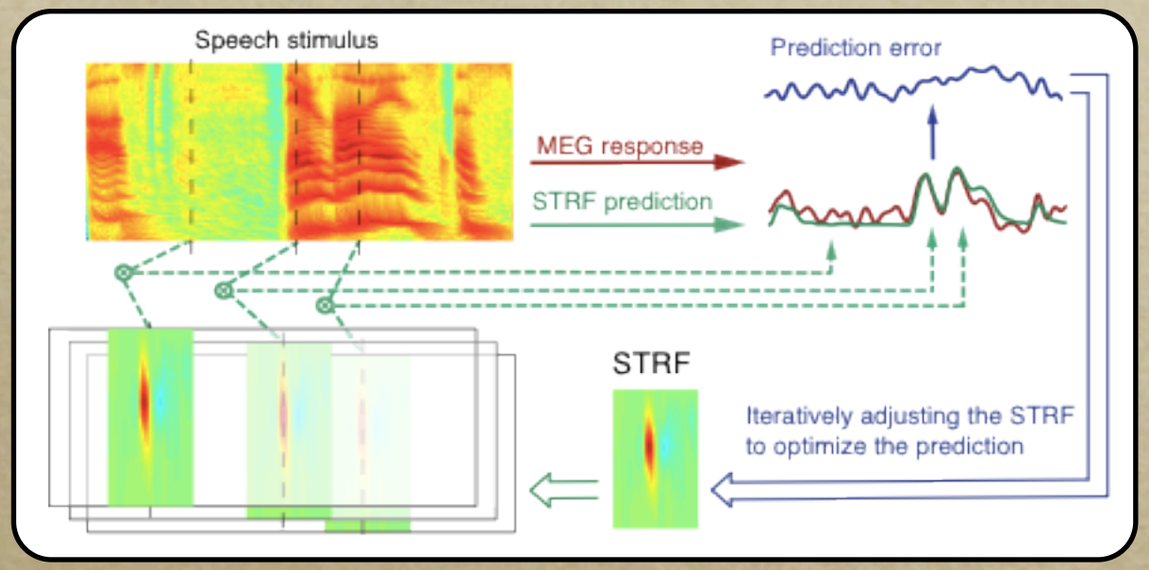
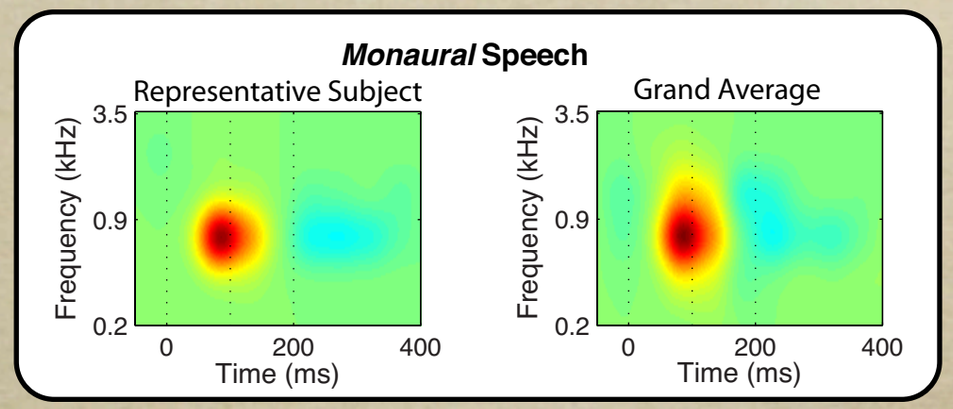
MEG STRF from Speech

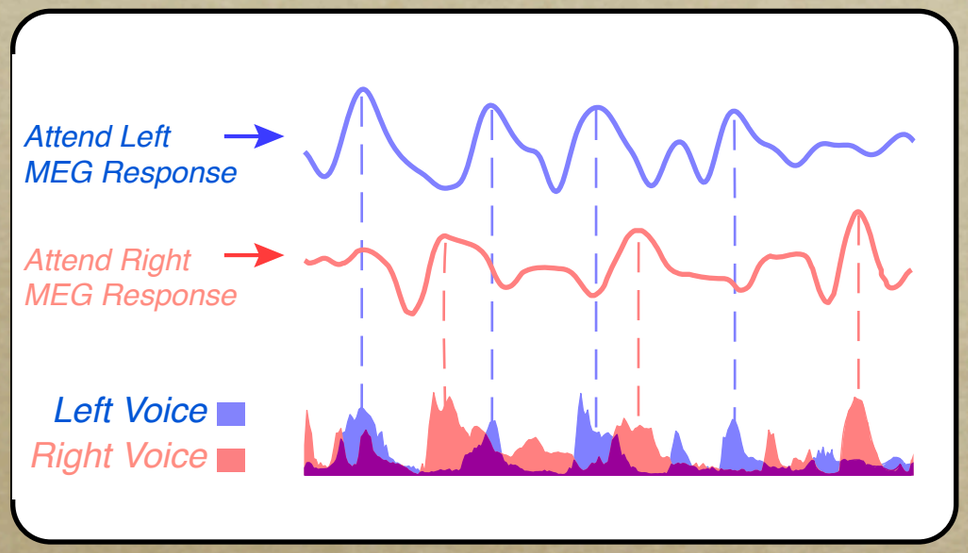




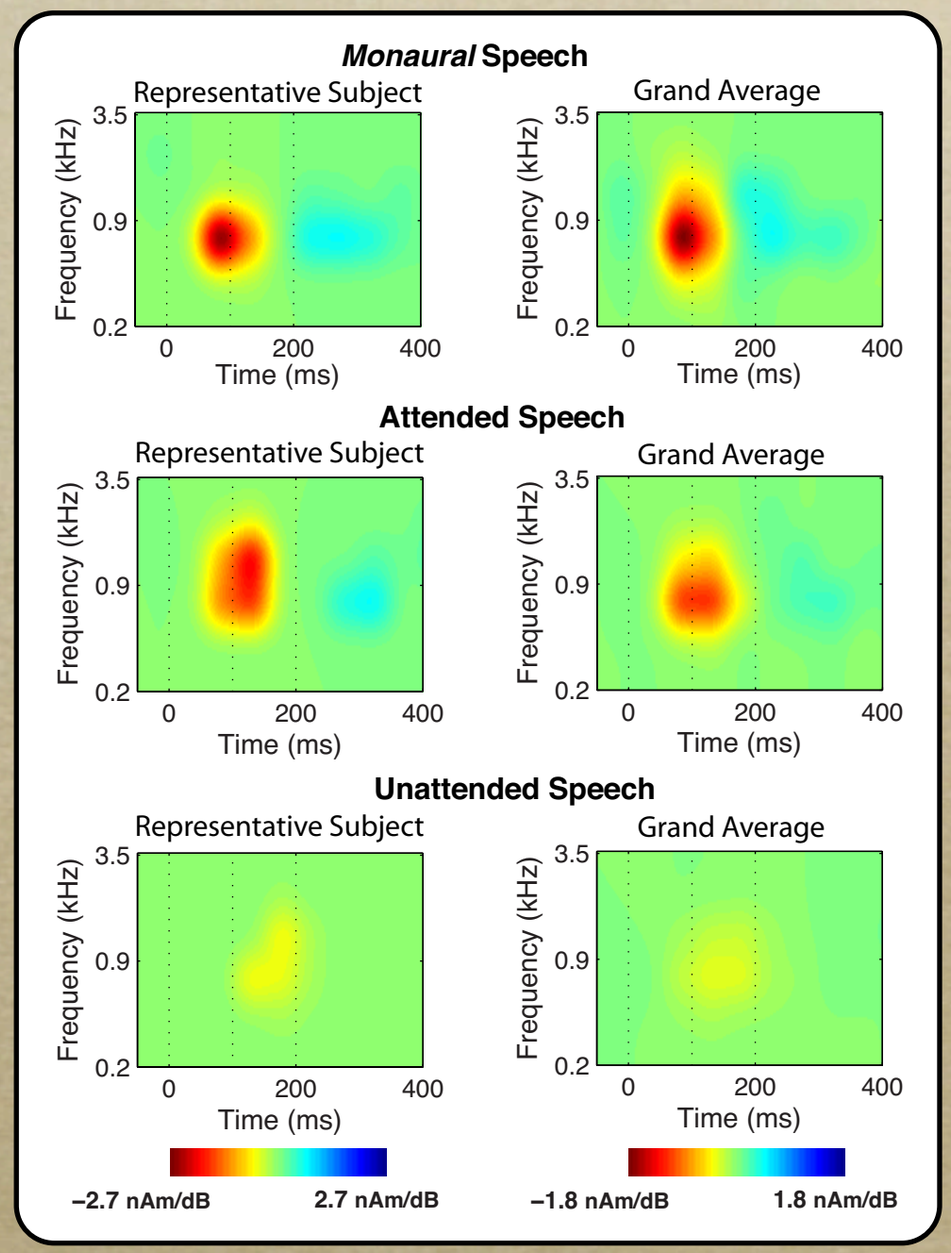
- *Stimulus: 2 minutes of monaural speech*
- *Speech Spectrogram → MEG Response*
- *Method: Boosting with cross validation*
- *Accuracy comparable to individual AI neuron*

Ding & Simon, Submitted

Separation of Dichotic Speech



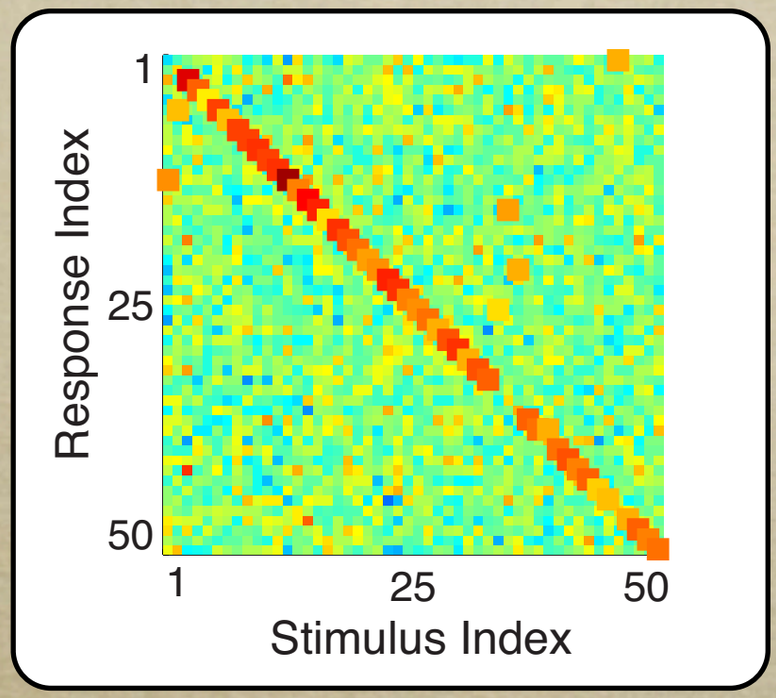
- *Stimulus: 2 minutes of dichotic speech*
- *STRF robust against spatial masking of speech*
- *Strong attentional modulation of neural representation (STRF)*



Ding & Simon, Submitted

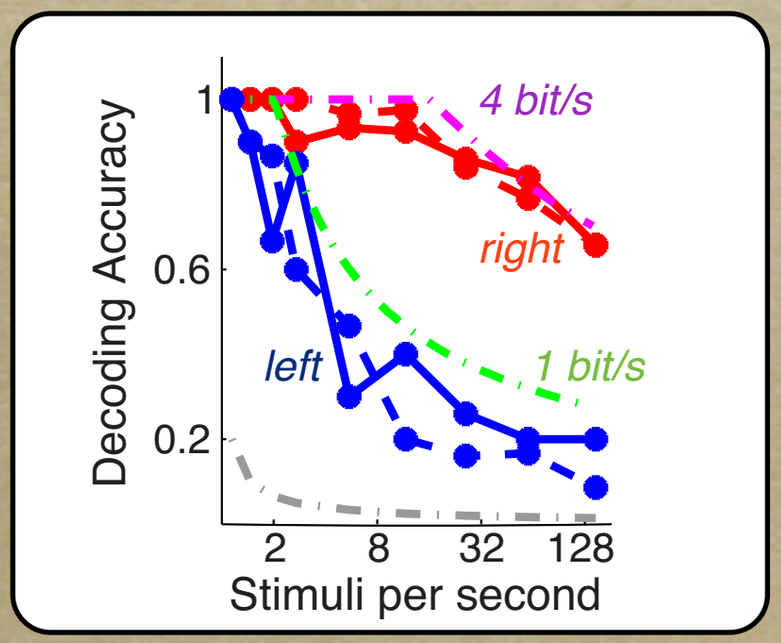
Information Content in MEG Signal

- *Cross-correlation of speech envelope & MEG response **diagonal** for long segments*
- *Stimulus Decoding: strongest correlation = best stimulus guess*
- *Predictions worsen when too many small-duration segments*
- *Conservative estimate (linear)*
- *Stimulus decoding accuracy:*
  - *4 bit/s in right hemisphere*
  - *1 bit/s, in left hemisphere*



right hemisphere

50 x 1.2 s duration segments



Ding & Simon, Submitted

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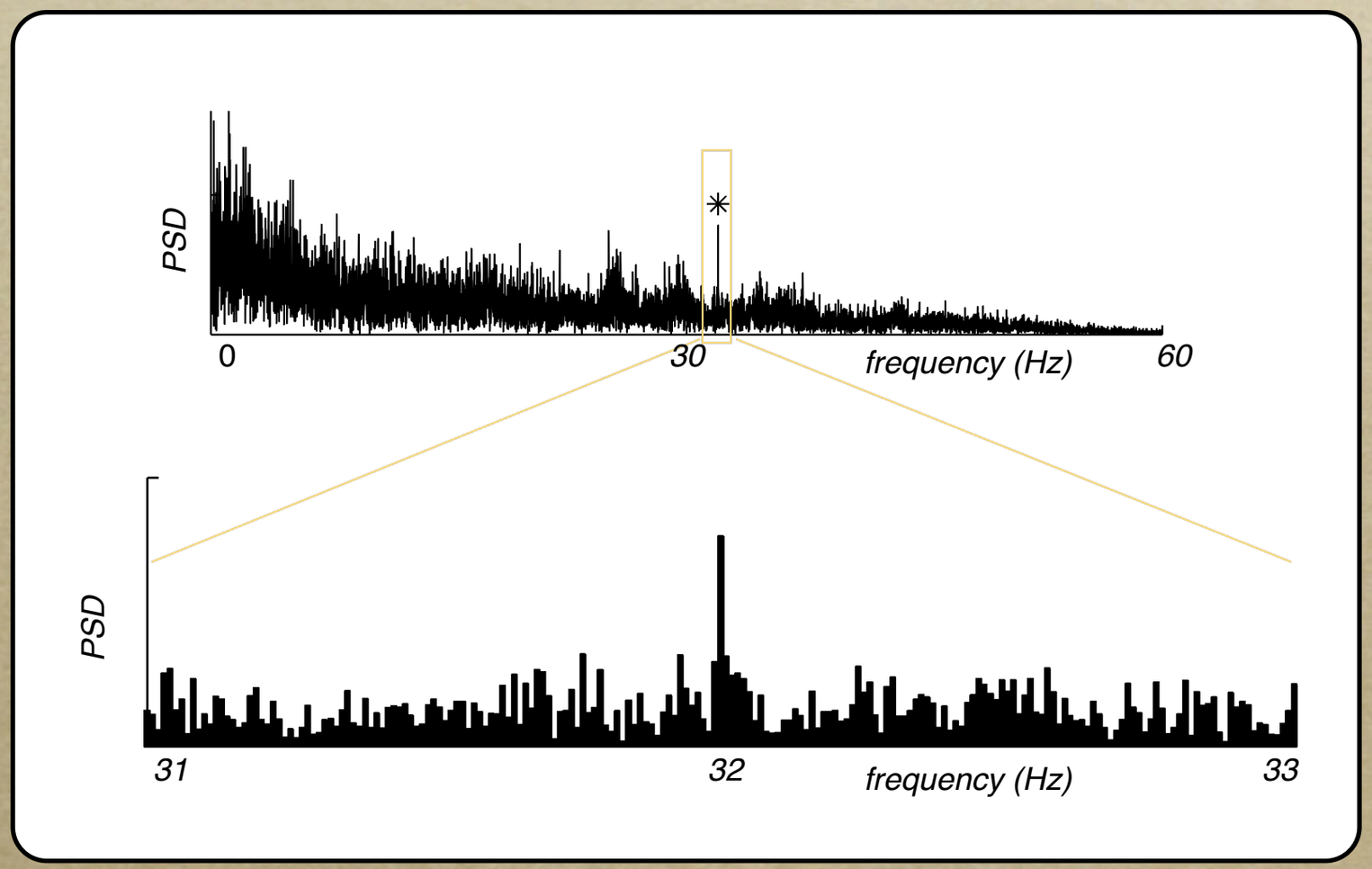
MEG Frequency Response

Stimulus:
Amplitude Modulation
at 32 Hz

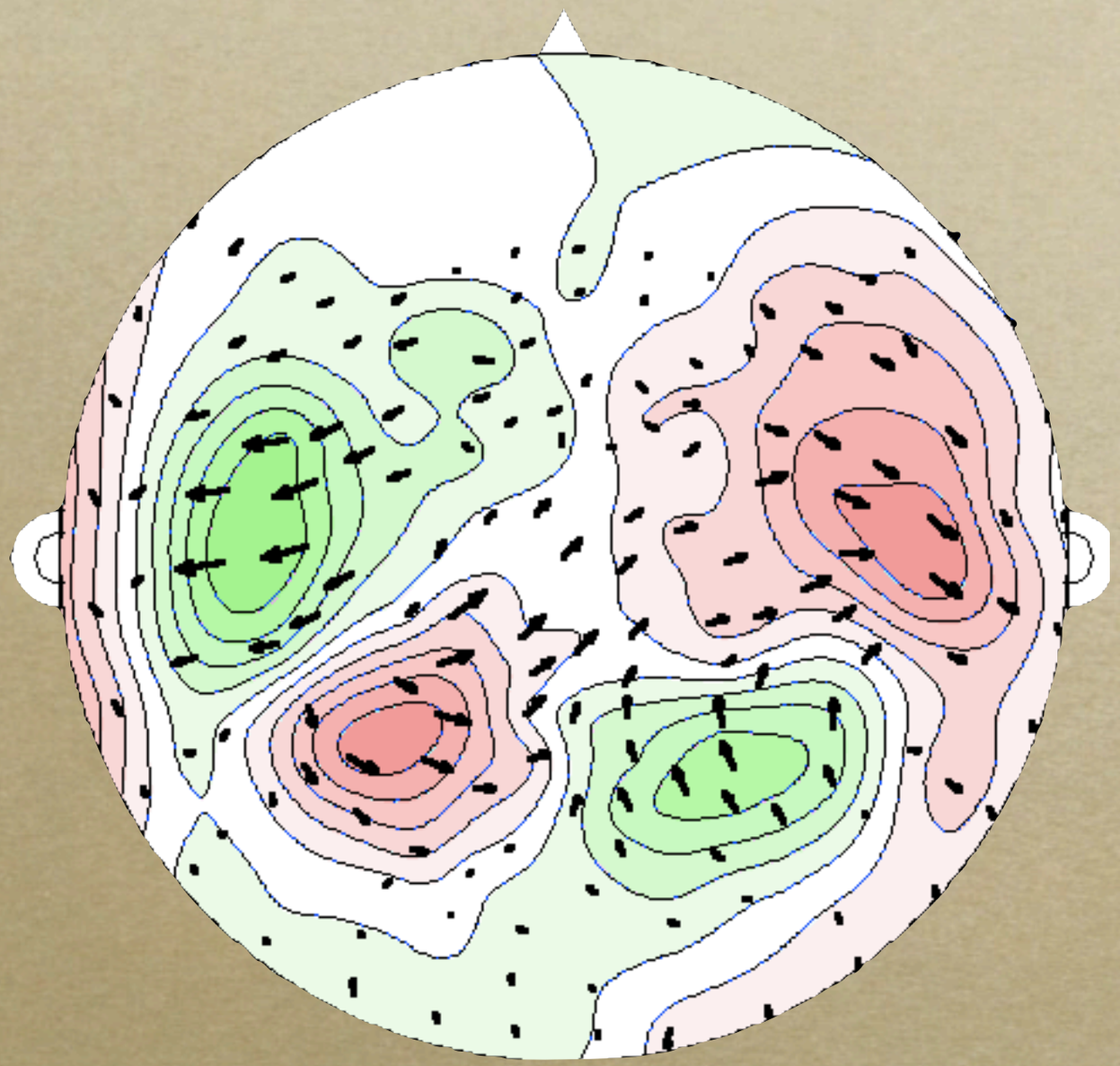
400 Hz tone carrier
100 trials @ 1 s
(concatenated)



Amplitude + Phase...

Whole Head Steady State Response

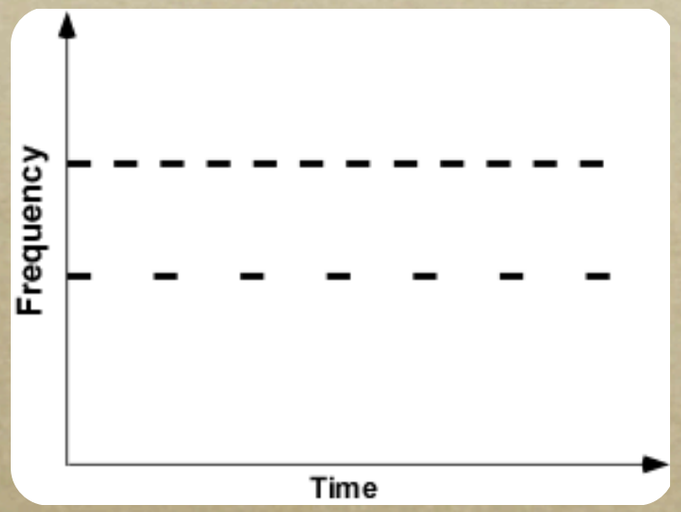
Phasor Isofield Contour Map



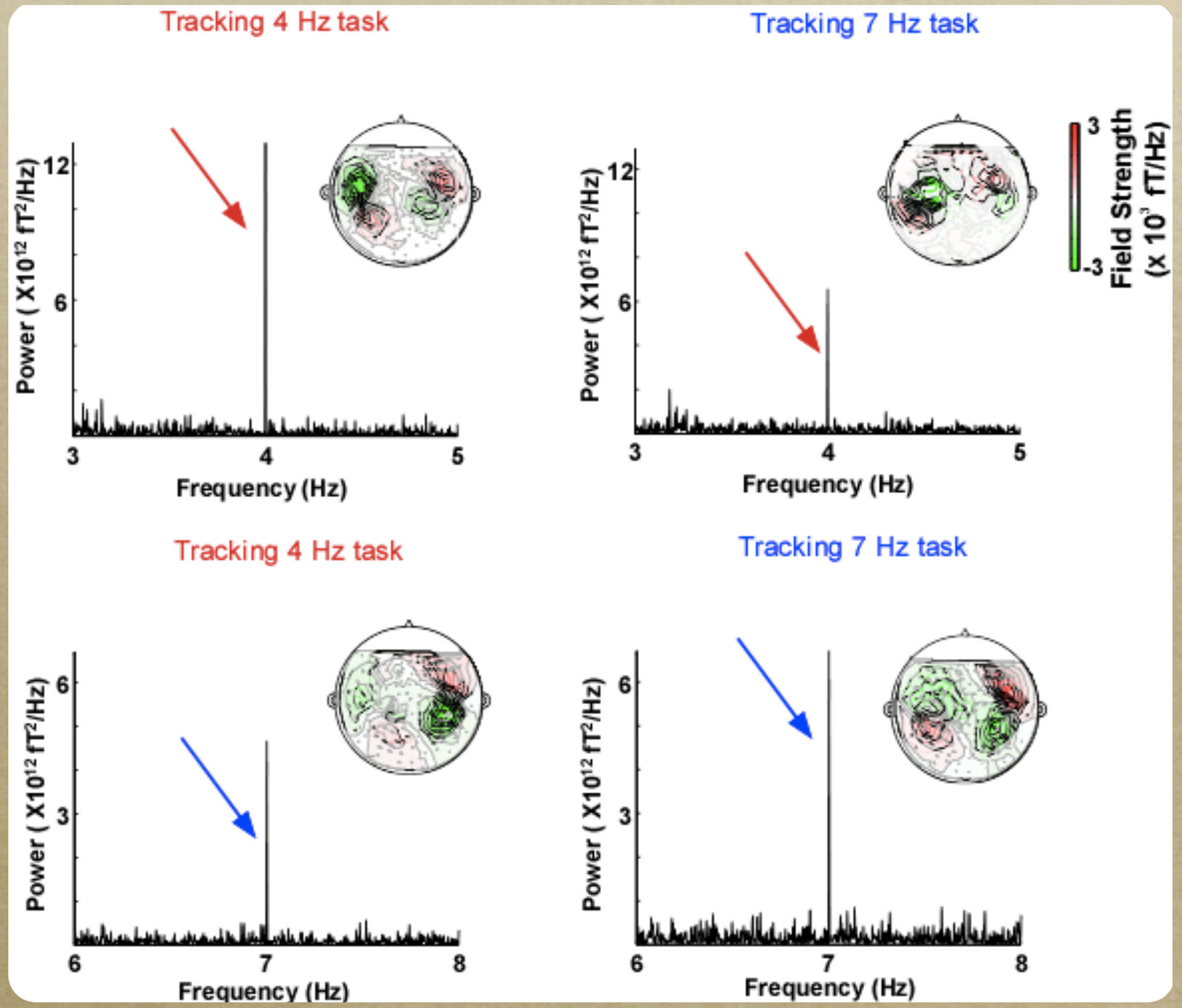
f = 32 Hz

Simon and Wang, J. Neurosci. Methods (2005)

Example: Auditory Streaming

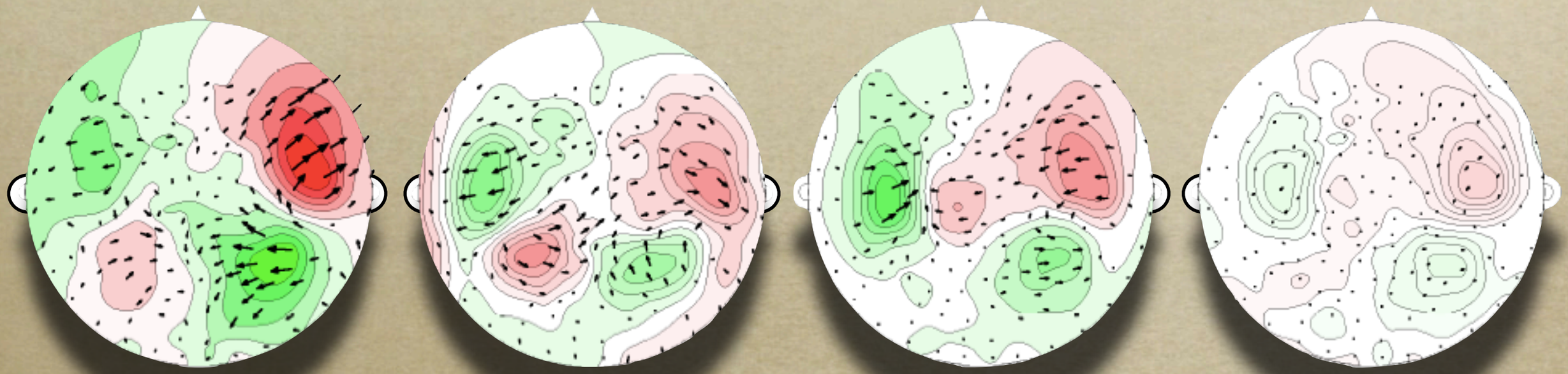


- *Stream Segregation with Competing Foregrounds*
- *Attentional Modulation of Neural Representation*



Xiang, Simon & Elhilali, J. Neuroscience (2010)

Whole Head Transfer Function



16 Hz

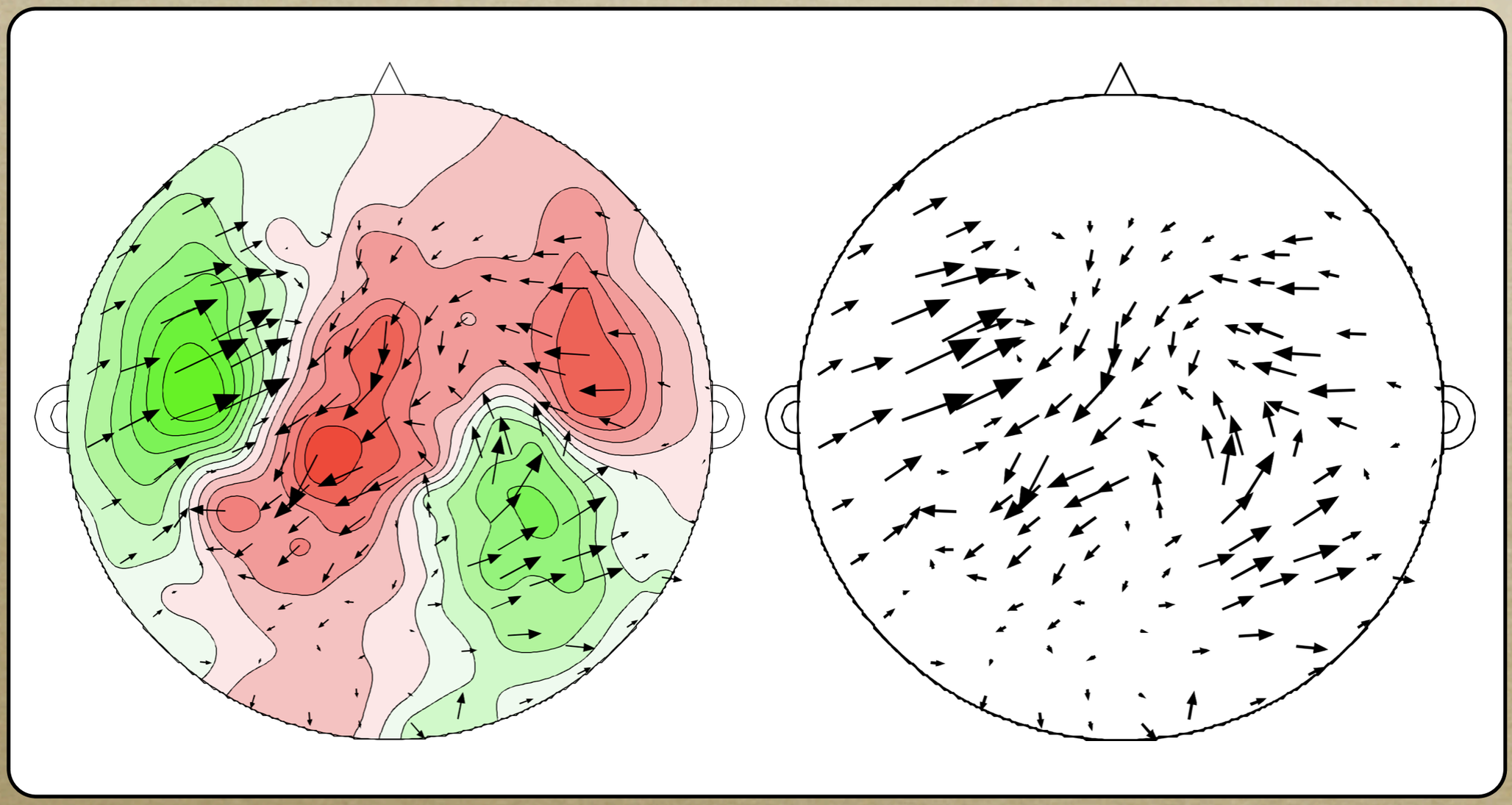
32 Hz

48 Hz

64 Hz

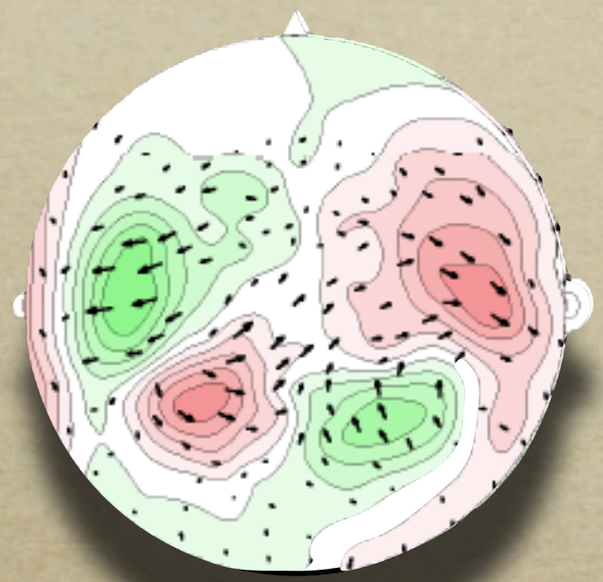
Complex Magnetic Field

with / without generated contours

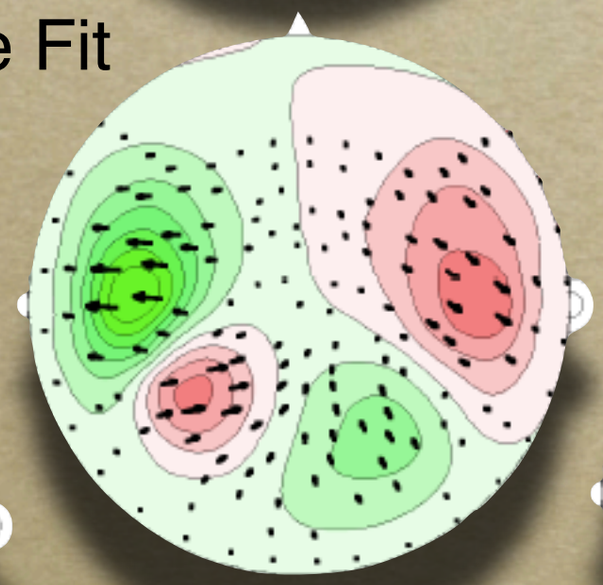


Current-Equivalent Dipoles

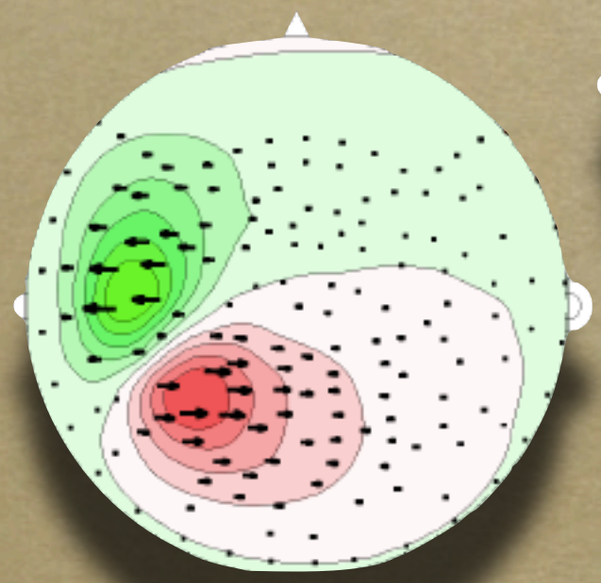
Raw Magnetic Field Data



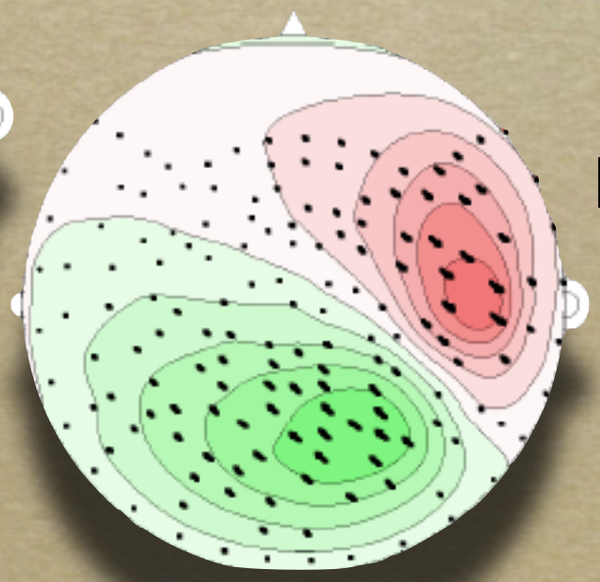
Two Dipole Fit



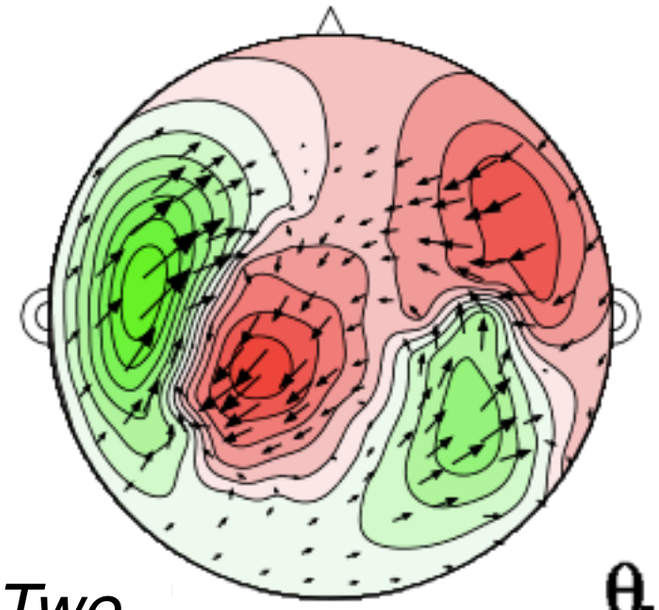
Left Hemisphere Current Equivalent Dipole



Right Hemisphere Current Equivalent Dipole



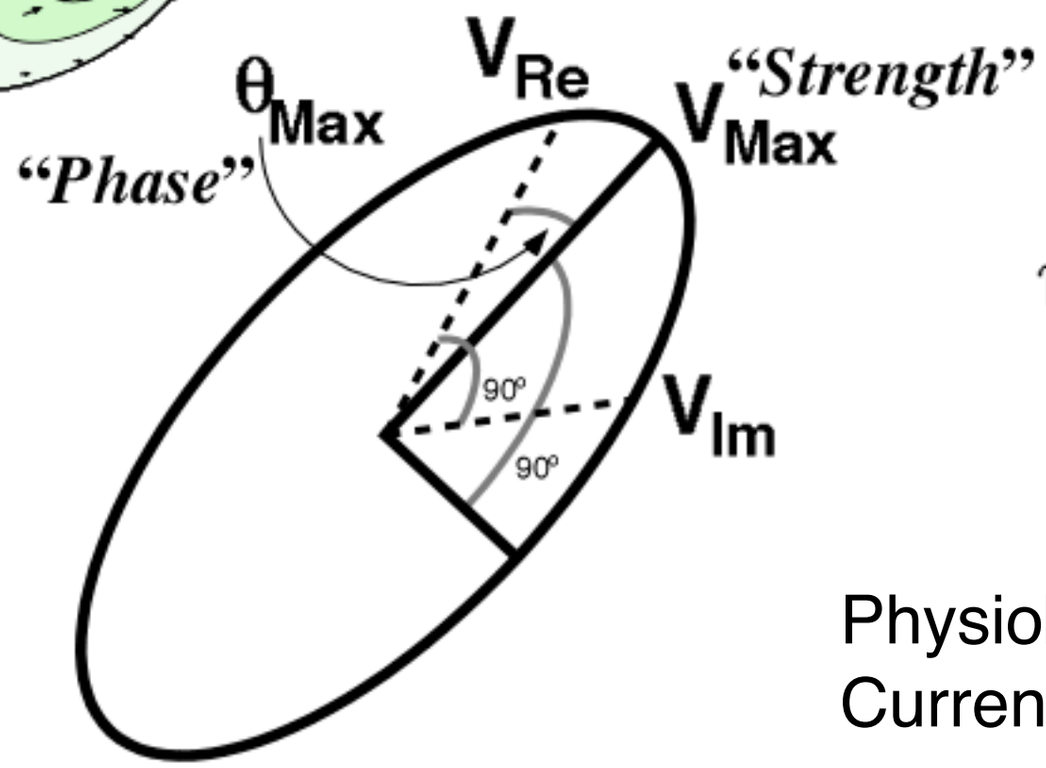
Complex Neural Current Sources



Two Dipole Fit

$$\vec{V} = \vec{V}_{Re} + i\vec{V}_{Im}$$

$$\vec{V}(\theta) = \vec{V}_{Re}\cos(\theta) + \vec{V}_{Im}\sin(\theta)$$



$\hat{V}_{Max}, \hat{V}_{Min}$ *Orientations*

"Sharpness"

$$\eta = \frac{|V_{Min}|}{|V_{Max}|}$$

$$0 < \eta < 1$$

Physiologically Simple Current Sources: $\eta = 0$

Simon and Wang, J. Neurosci. Methods (2005)

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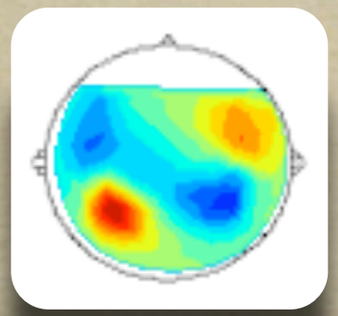
Separating Signals

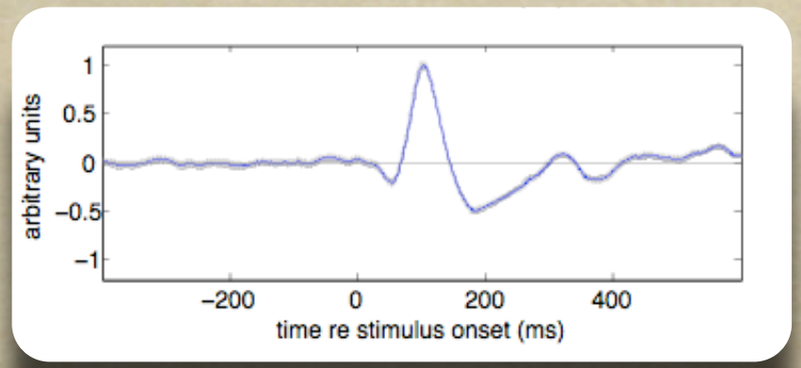
from each other and/or from noise

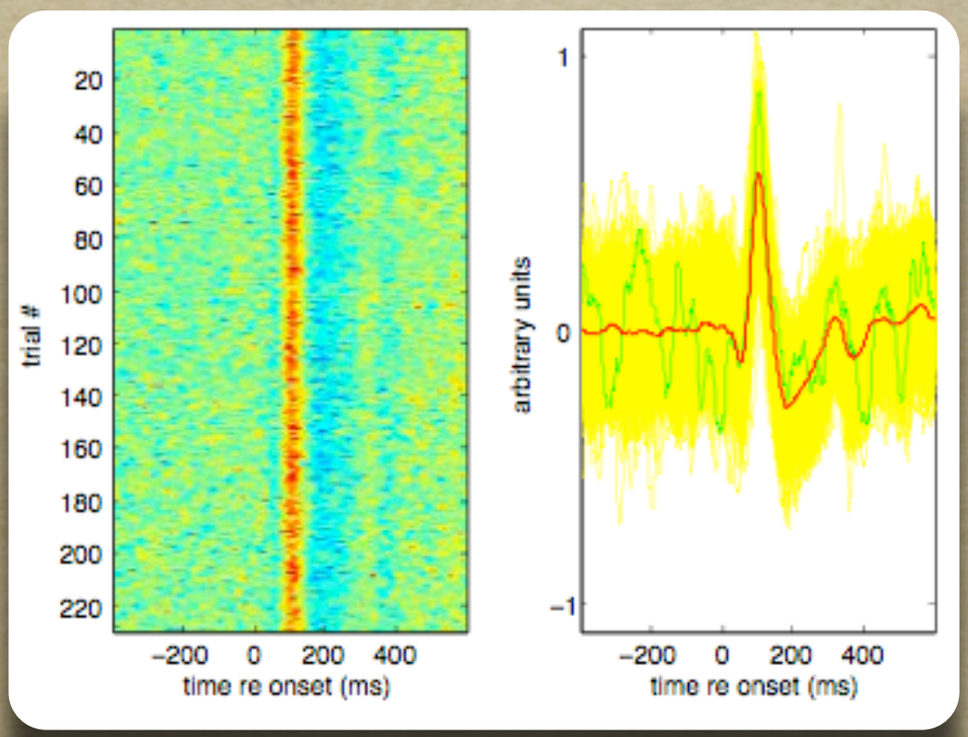
- *Data driven spatial filtering:*
  many available methods—ICA, PCA, DSS
- *Generate spatial filters & their outputs*
  (“components”)
- *DSS: Denoising Source Separation:*
  Särelä & Valpola (2005)
- *DSS components ordered by reproducibility*
  - *1st component “maximally reproducible” = most stimulus driven*

DSS Example

- *Most reproducible filter & component*
- *Optimally filters **out** trial-to-trial-variable signal = neural noise*
- *Filter can be applied to other signals, e.g. single trials*



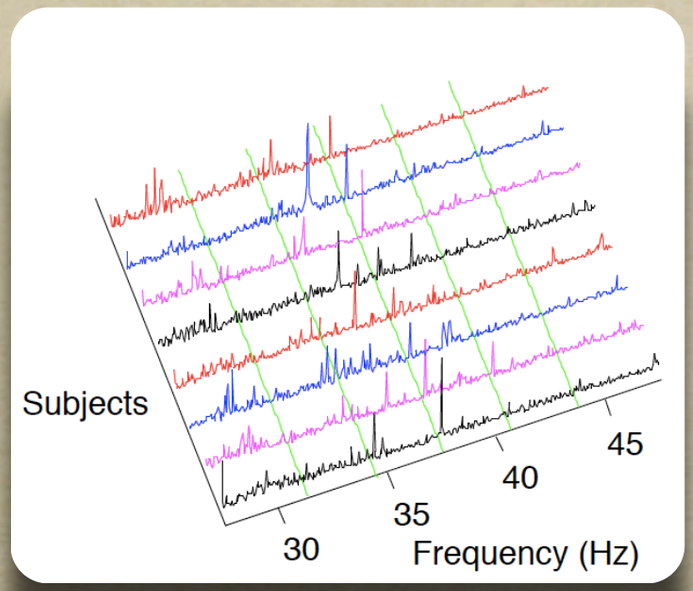




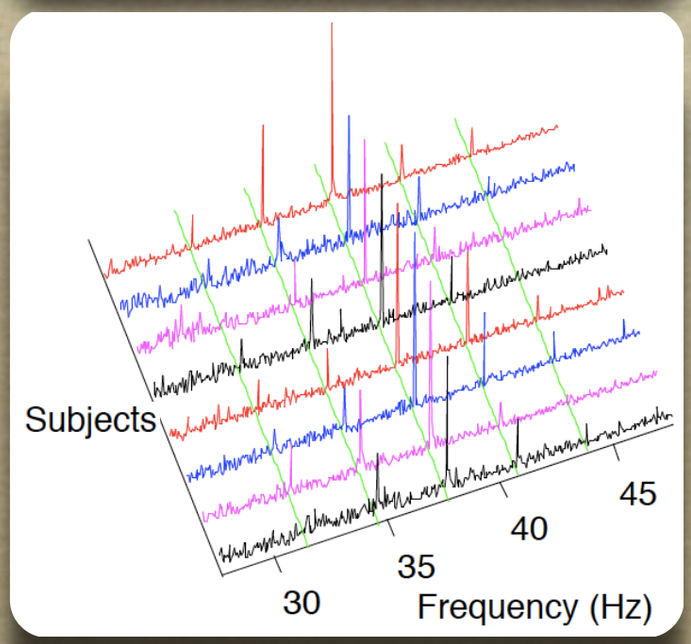
de Cheveigné & Simon, J. Neurosci. Methods (2008)

DSS Example: Spectral

Frequency Spectrum before DSS



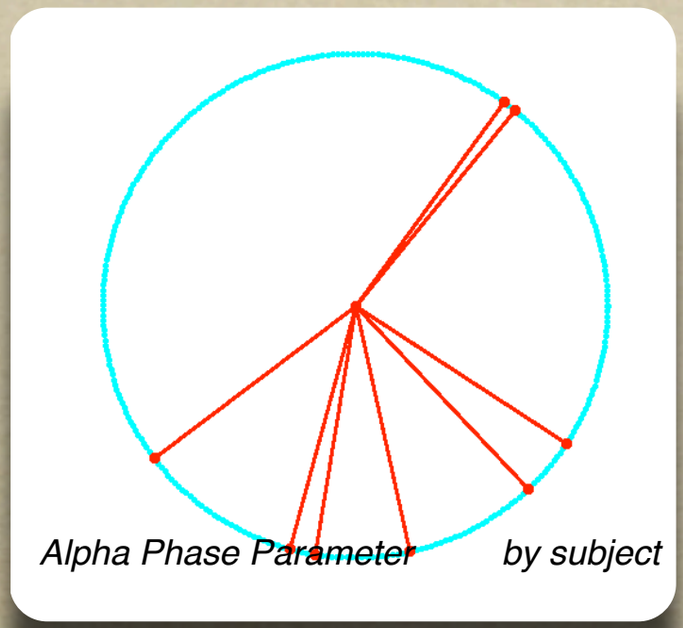
Frequency Spectrum after DSS



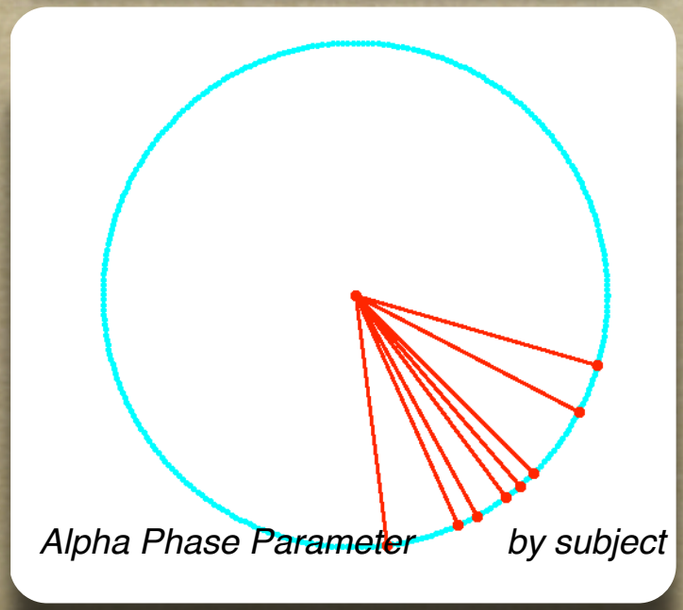
Ding & Simon, J. Neurophysiol (2009)

DSS Examples: Phase

Phasor Spread before DSS



Phasor Spread after DSS



Ding & Simon, J. Neurophysiol (2009)

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Collaborators

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Victor Grau-Serrat
Ling Ma
Raul Rodriguez
Juanjuan Xiang

Collaborators' Students

Julian Jenkins
Huan Luo

Undergraduates

Marko Modric

Past Undergraduates

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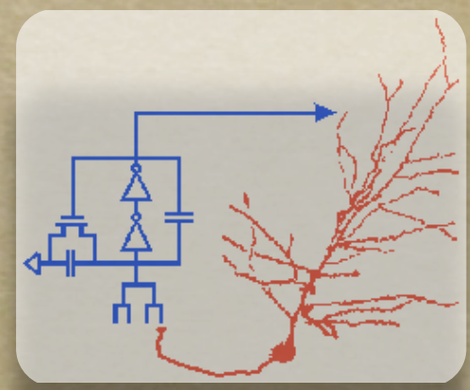
Nicholas Asendorf
Sonja Bohr
Corinne Cameron
Julien Dagenais
Marisel Villafane Delgado
Kevin Kahn
Andrea Shome



Computational Sensorimotor Systems Laboratory

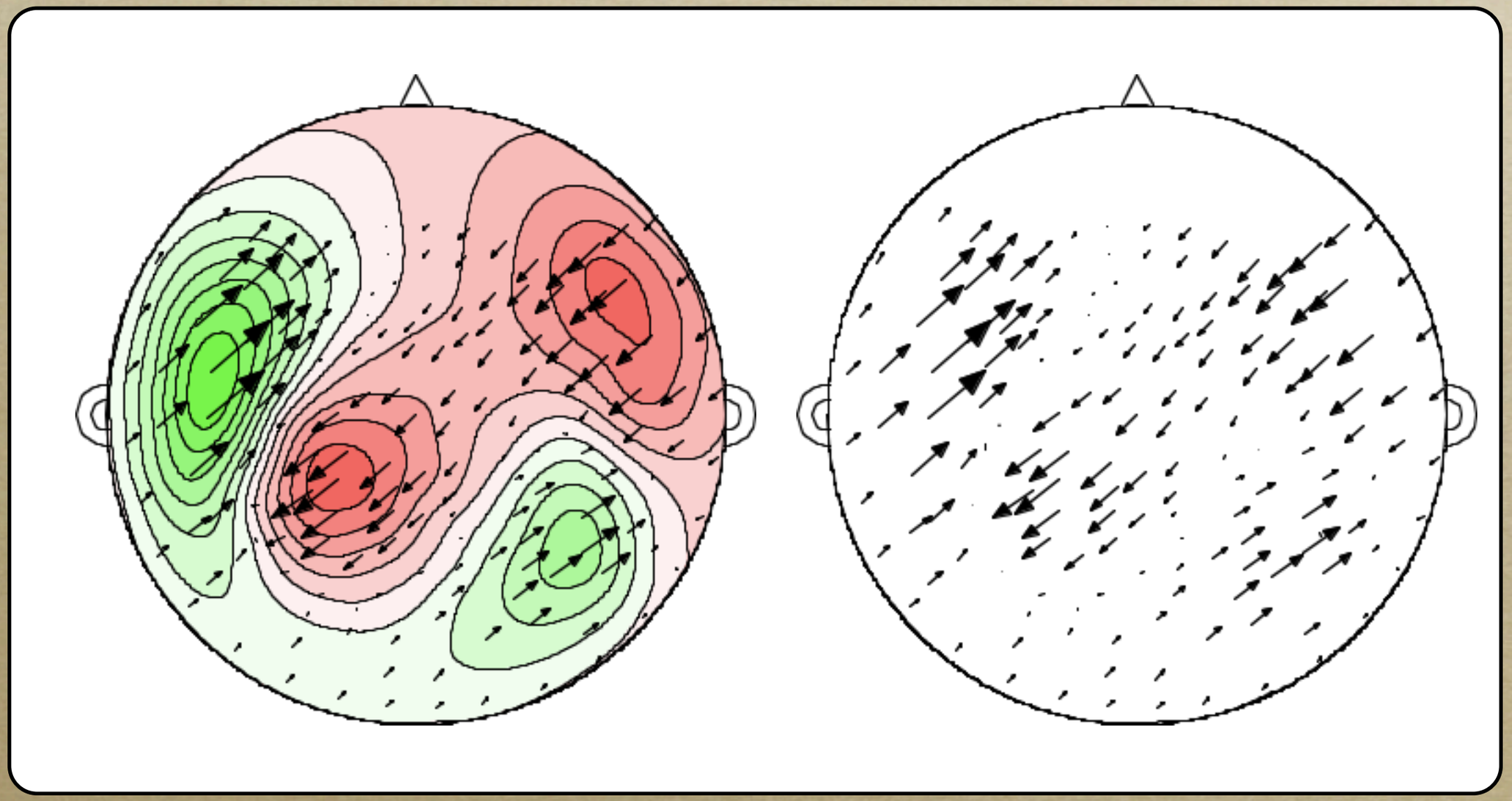
TENURE-TRACK ASSISTANT PROFESSOR: SENSORY NEUROBIOLOGY

The Department of Biology at the University of Maryland, College Park invites applications for an Assistant Professor in **sensory neurobiology**. We seek an outstanding candidate taking experimental and/or theoretical approaches to major questions in sensory neurobiology at the molecular, cellular, and/or organismal levels. Applicants must have a doctorate degree and should have developed, or demonstrate the potential to develop, an outstanding research program and a record of extramural funding. Applicants should also exhibit a commitment to excellence in teaching. Postdoctoral experience is preferred.

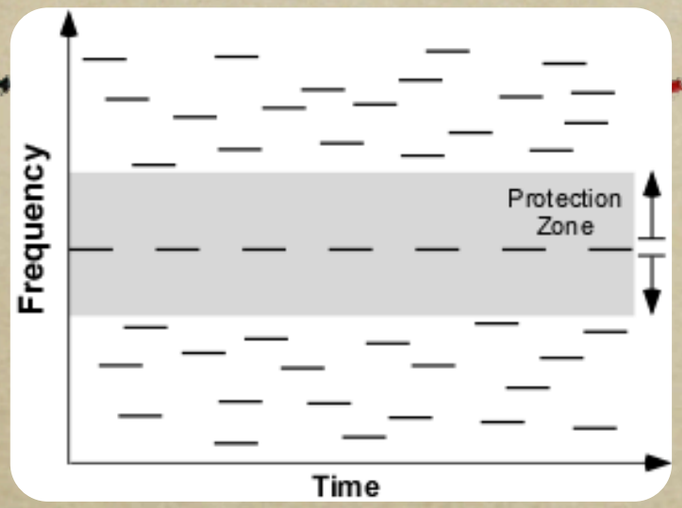
Applicants should apply electronically to https://jobs.umd.edu, specifying Sensory Neurobiology, Dr Catherine Carr, Search Committee Chair (position #116926). Applications should consist of a single PDF file containing (1) a letter of application, (2) a curriculum vita, (3) a statement of research interests and plans, (4) a statement of teaching experience and interests. PDFs of selected publications can be submitted as supplementary information if desired. Please arrange for three recommendation letters to be submitted directly to https://jobs.umd.edu, specifying the same information as above. For best consideration, applications should be complete by Dec. 30, 2010

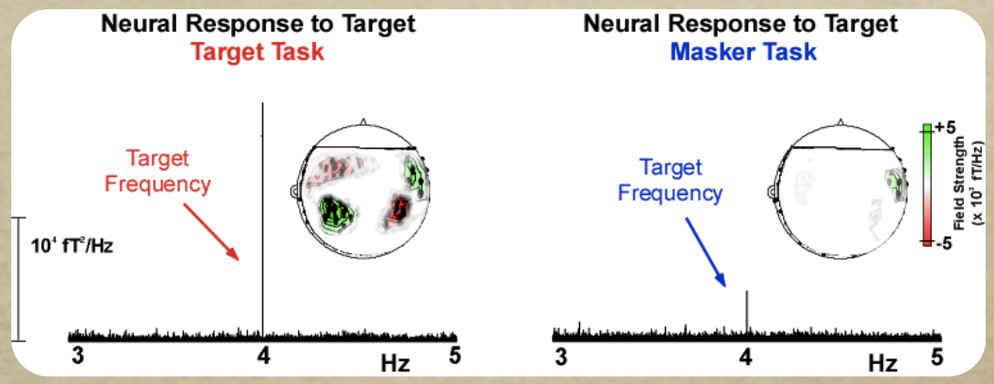
The University of Maryland is an equal opportunity/affirmative action employer. Applications from minorities and women are encouraged.

Single Orientation Current Sources

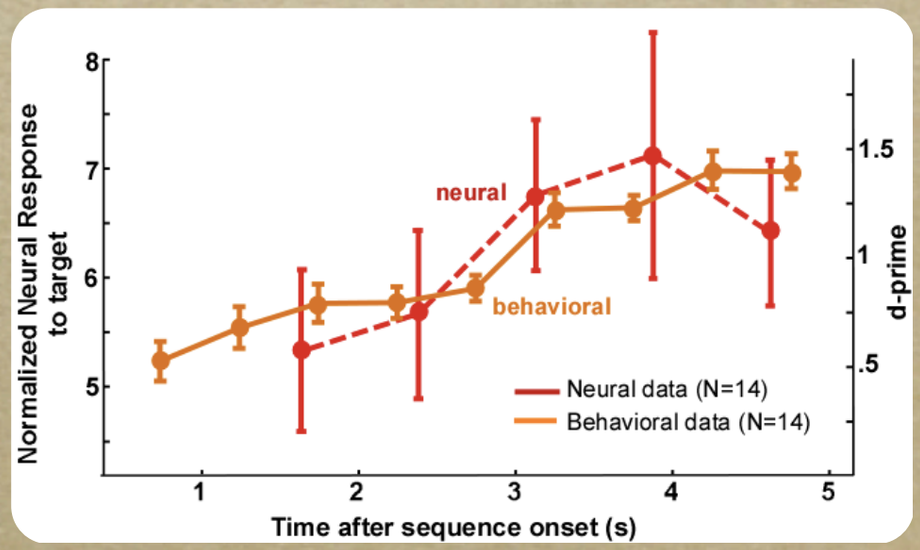


Auditory Streaming I





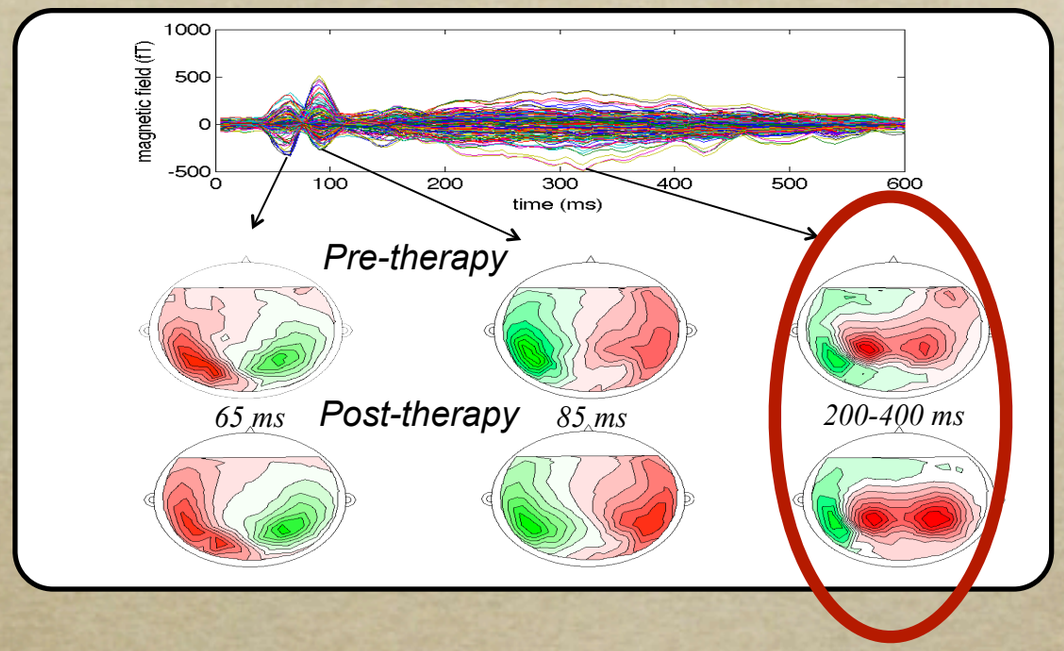
- *Stream Segregation & MEG*
- *Foreground vs. Background*
- *Attentional Modulation of Neural Representation*
- *Neural Correlate of Behavioral Buildup*

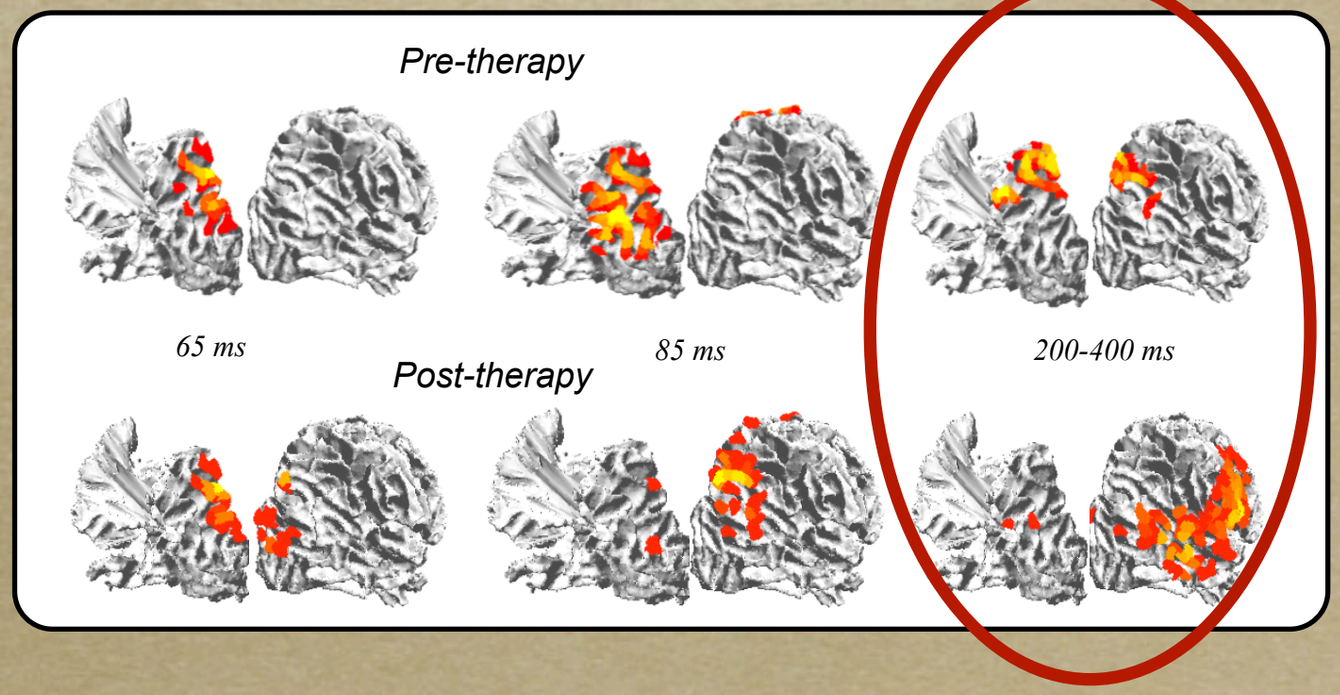


Interaction between attention and bottom-up saliency mediates the representation of foreground and background in an auditory scene. Elhilali, Xiang, Shamma & Simon (2009) PLoS Biology

Neural Correlates of Therapy for

- *Combine MRI with MEG*
- *Competing Neural Source Localization Algorithms not Unique*
- *Campus MRI system on track for summer 2011*





In Progress, Ding, Simon & Faroqi-Shah