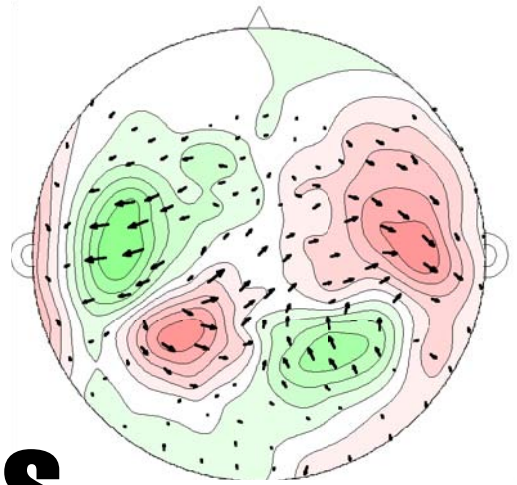
Phase-locking in Human Auditory Cortex to Spectrotemporal Modulations



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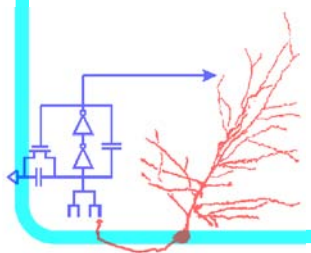
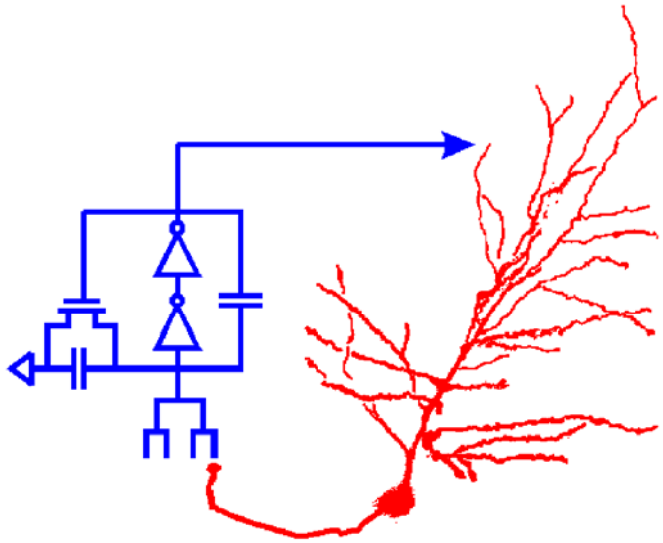


Computational Sensorimotor Systems Laboratory



Yadong Wang

Juanjuan Xiang
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David Poeppel
Timothy Horiuchi

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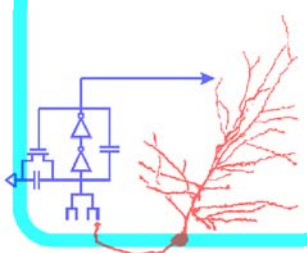
Jeff Walker

Outline

- Introduction & Background: MEG
- Auditory Steady State Response (SSR)
- Experiments: Design, Results & Implications
- Related Lab Activity



MEG – Magnetoencephalography

- Simultaneous Whole Head recordings

  160 sensors (3 reference)

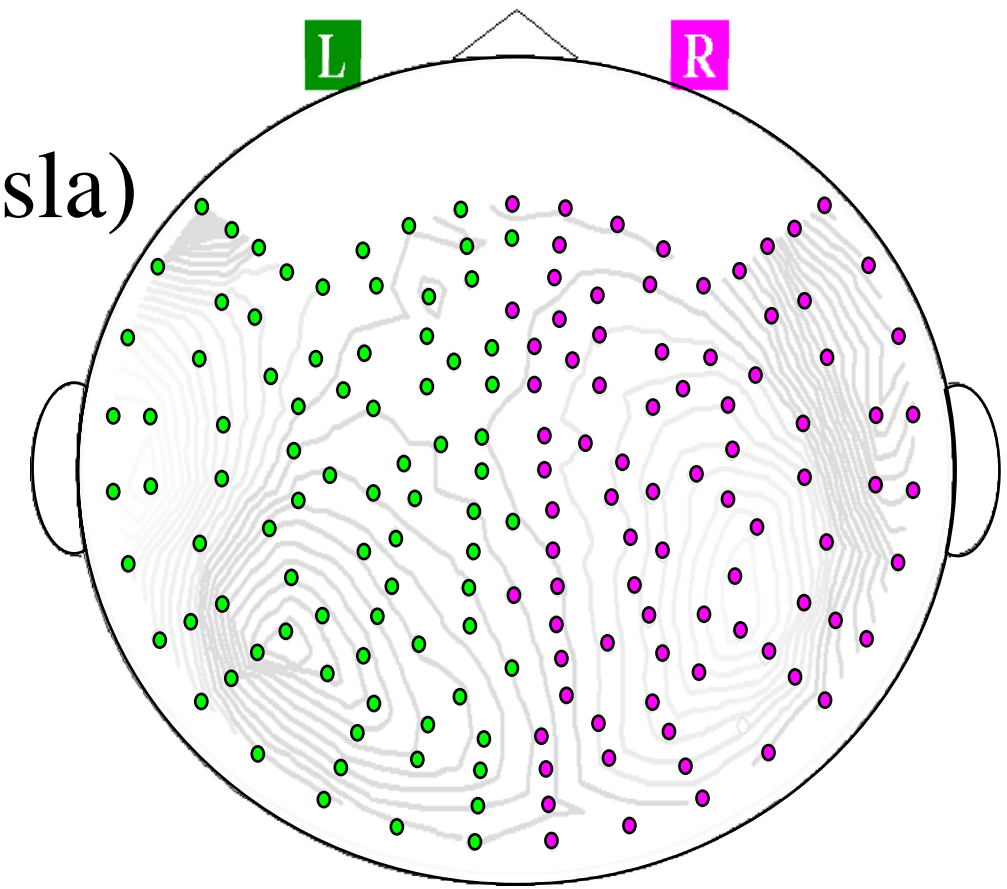
- Exquisitely Sensitive

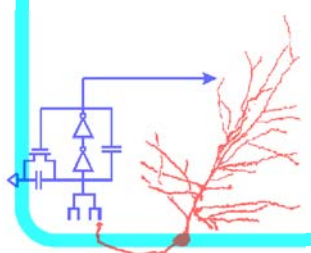
  ~ 100 fT (10^{-13} Tesla)

  ~ 10^4 neurons

- Temporal Resolution

  ~ 1 ms





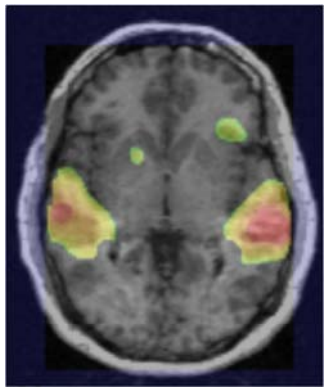
Functional Imaging

Non-invasive recording from human brain (Functional brain imaging)

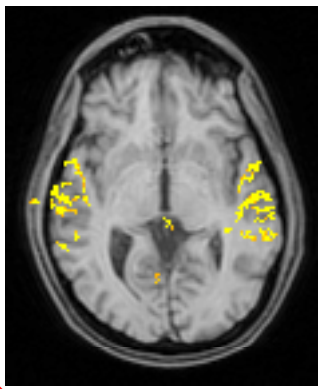
Hemodynamic techniques

Positron emission tomography
PET

Excellent *spatial resolution*
(~ 1-2 mm)
Poor temporal resolution
(~ 1 s)



Functional magnetic resonance imaging
fMRI

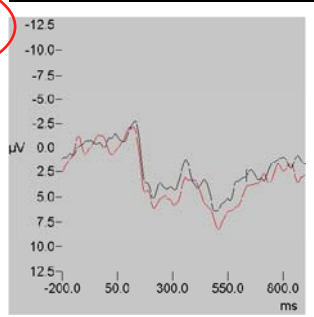


PET, EEG require across-subject averaging

fMRI and MEG can capture effects in single subjects

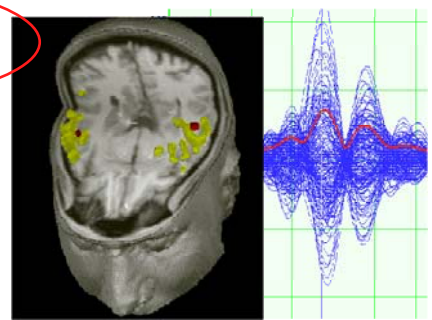
Electromagnetic techniques

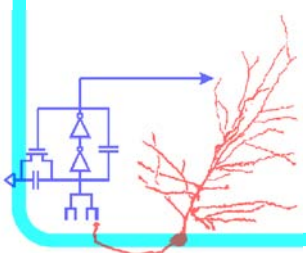
Electroencephalography
EEG



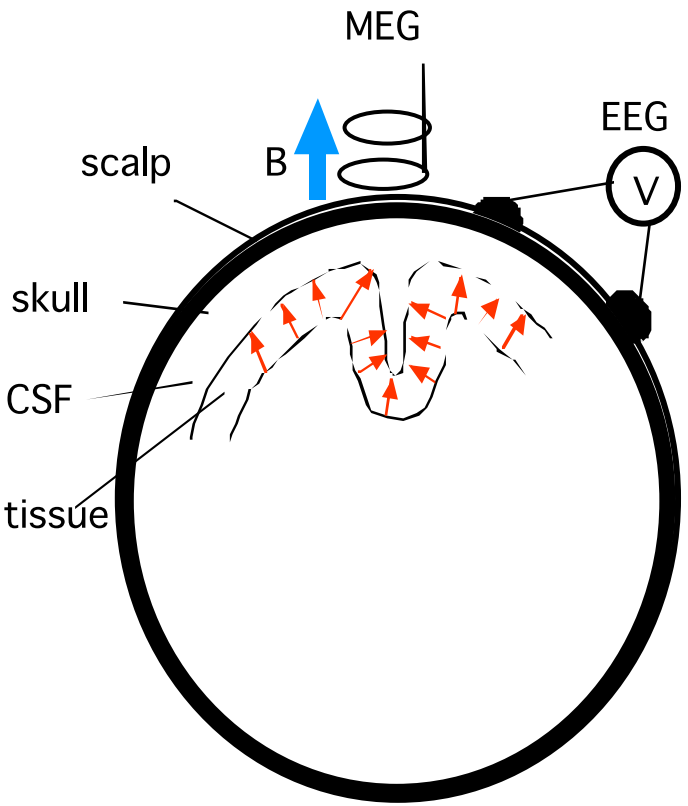
Poor spatial resolution
(~ 1 cm)
Excellent *temporal resolution*
(~ 1 ms)

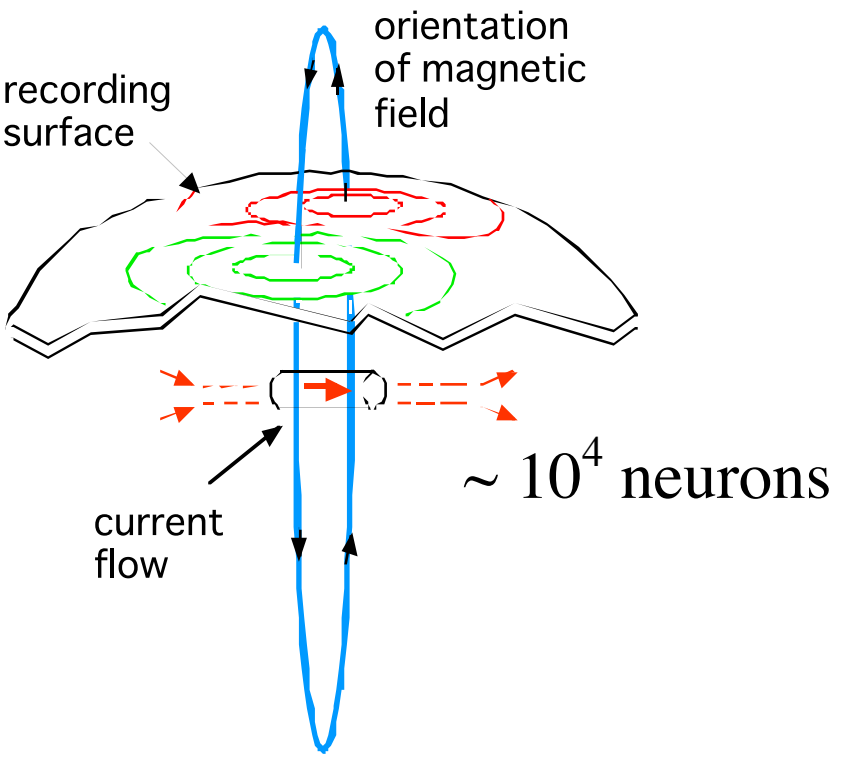
Magnetoencephalography
MEG

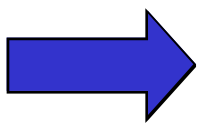




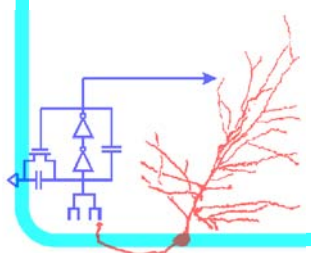
MEG Magnetic Signal







Non-invasive measurement
Direct measurement of Neural Activity

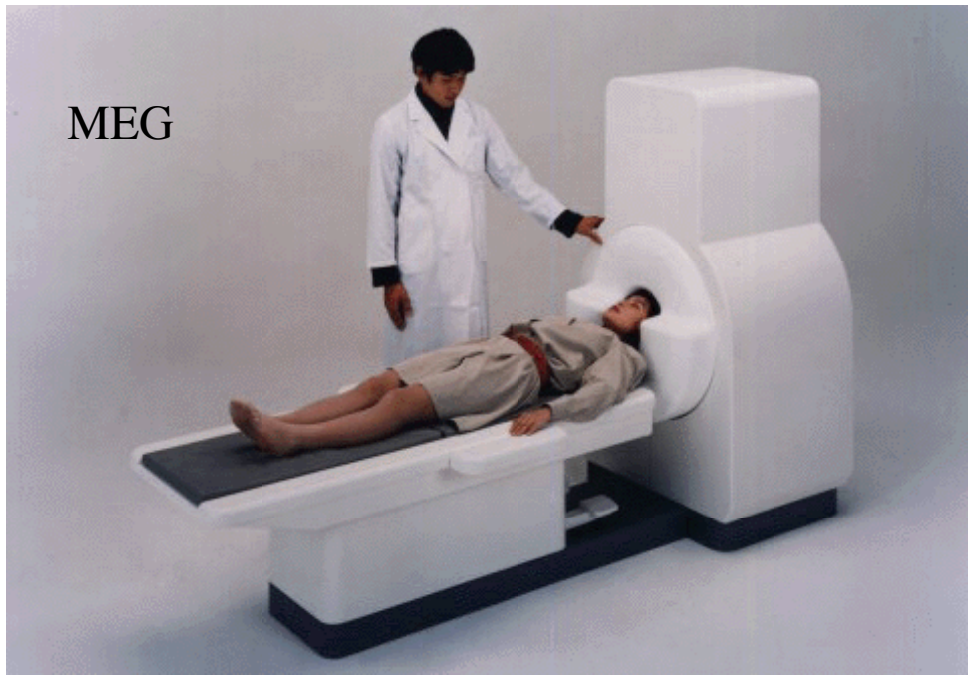


MEG compared to EEG

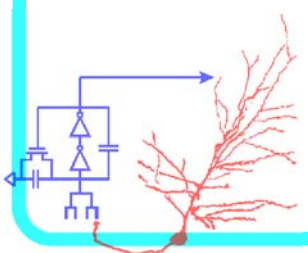
Temporal resolution high as EEG
Fast, easy set-up
Magnetic fields are not attenuated or distorted, unlike electric fields
Higher spatial resolution(?)

Expensive
Inverse problem worse? Better?

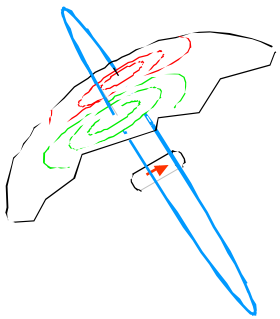
Complementary Techniques



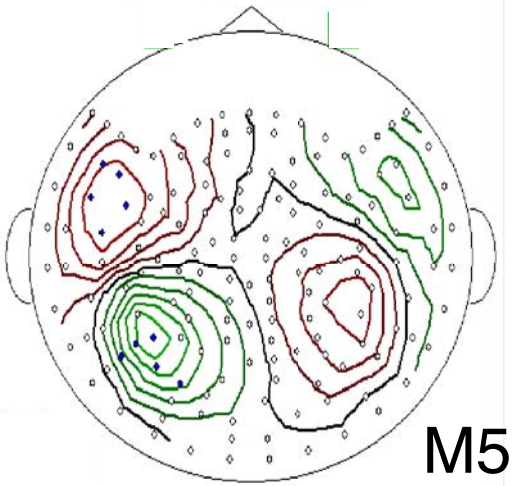
EEG



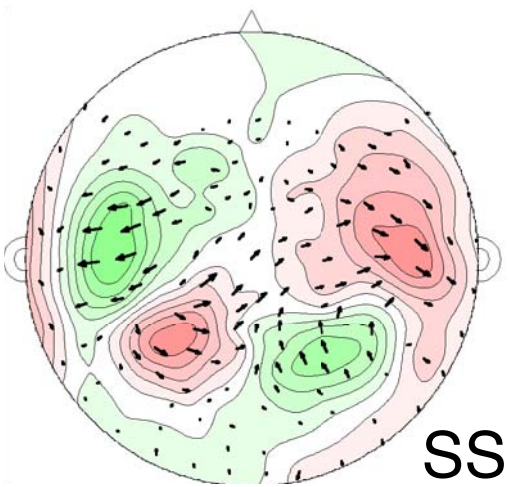
Auditory MEG Responses



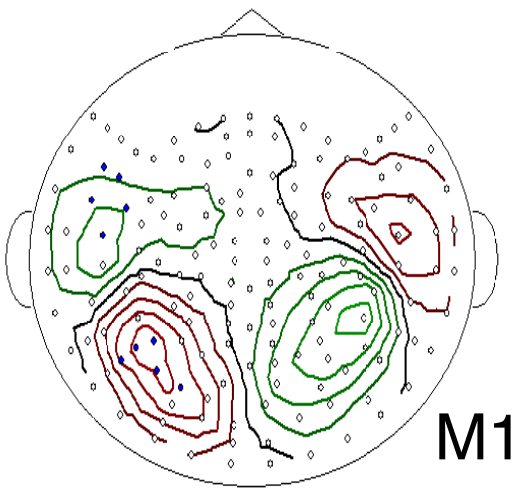
Auditory Responses
Lateralize Strongly!



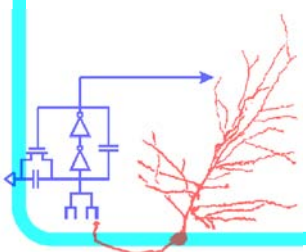
M50



SSR



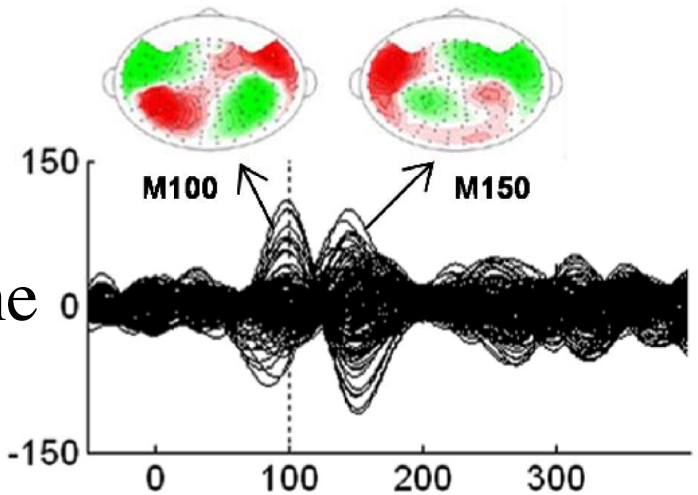
M100



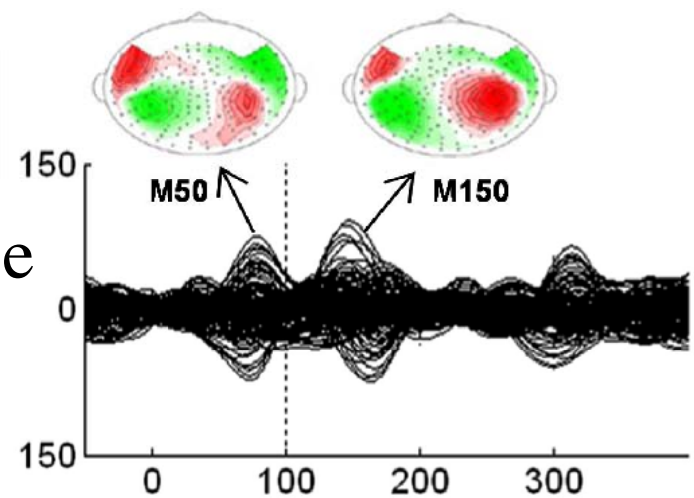
Time Course of MEG Responses

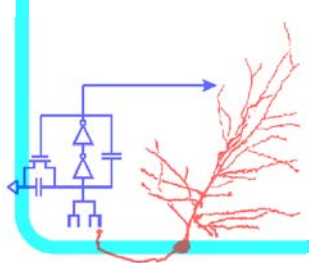
Evoked Responses
MEG Events Time-Locked
to Stimulus Event

Pure Tone



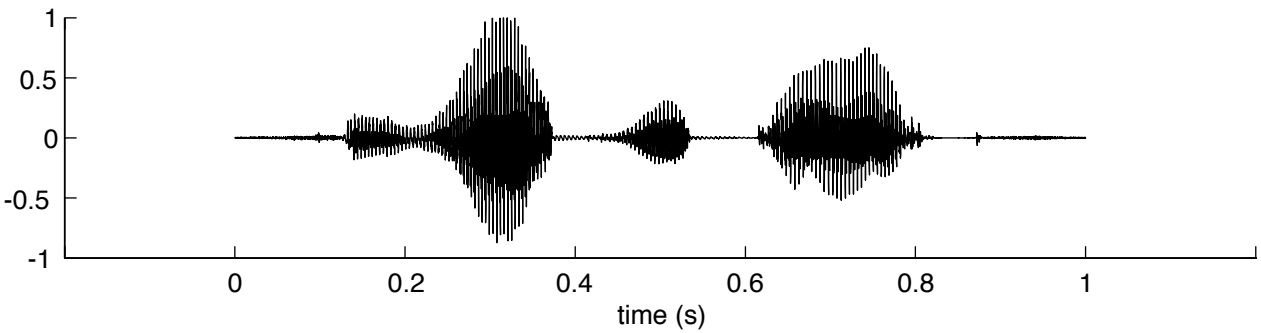
Broadband Noise



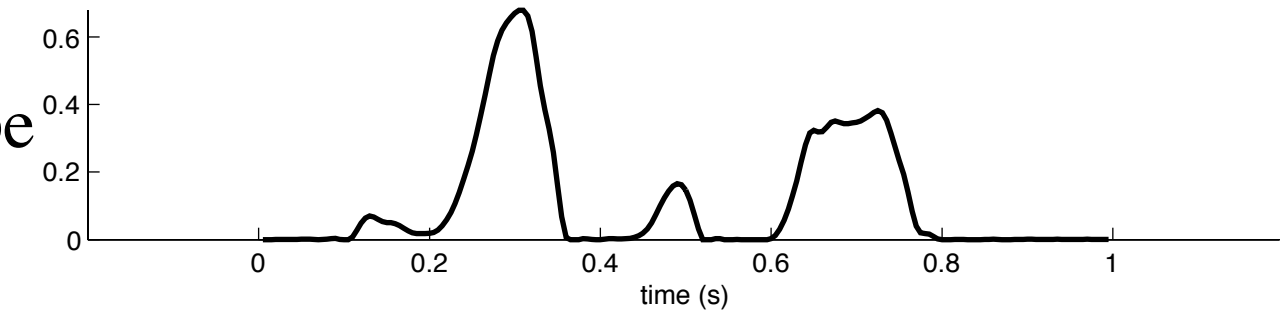


Time Course of Speech Response

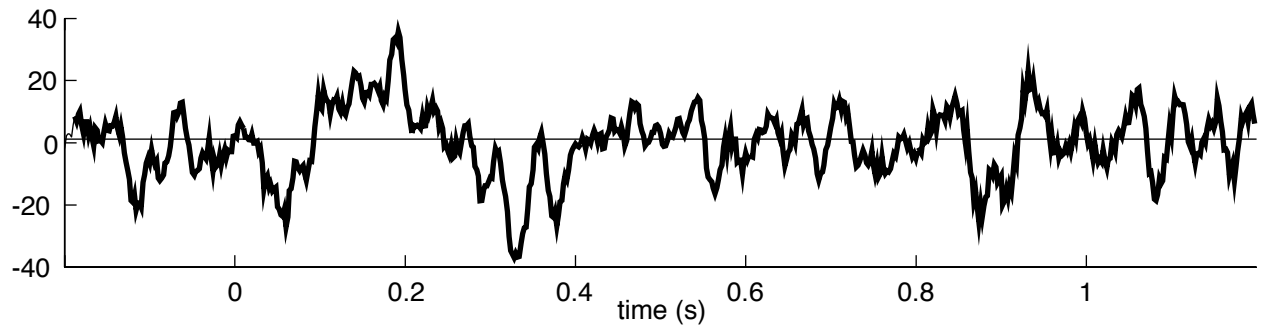
Stimulus



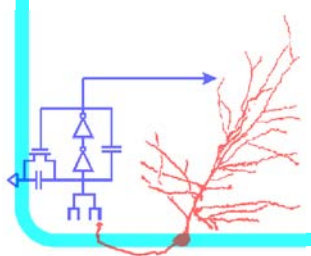
Stimulus Envelope



MEG Channel Response



What are the MEG Events?
What are the Stimulus Events?

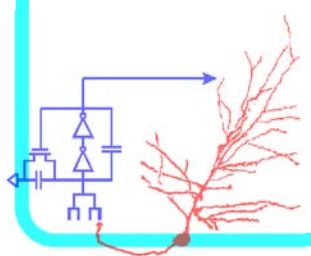


An Alternative to Time: Frequency

- Use Stimuli localized in Frequency rather than time
- Examine Response at Same Frequency
- Well Established Method:

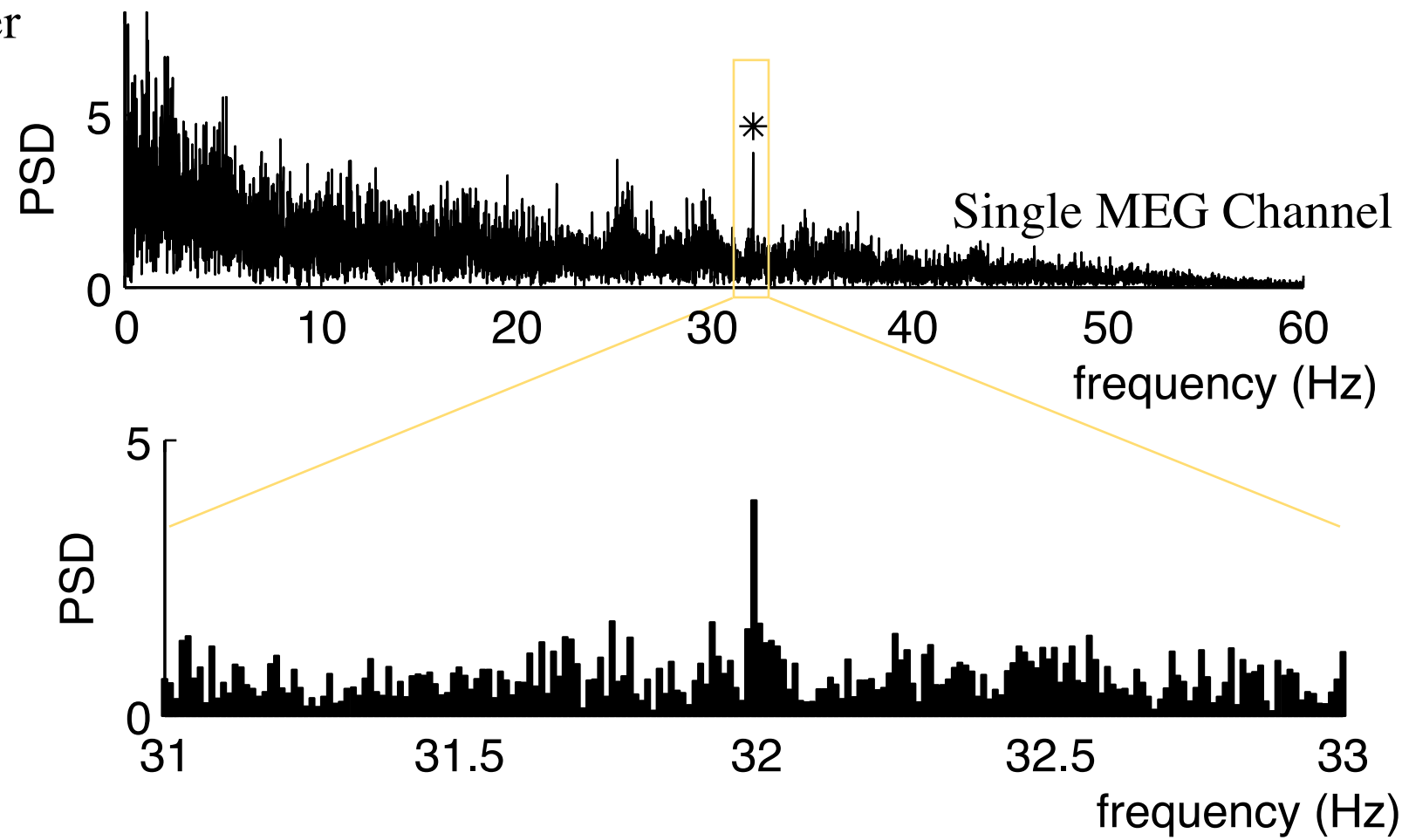
  Frequency Response or ***Transfer Function***
- Stimulus Modulated at Single Frequency:

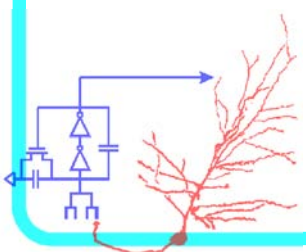
  Steady State Response (SSR)



Frequency Response

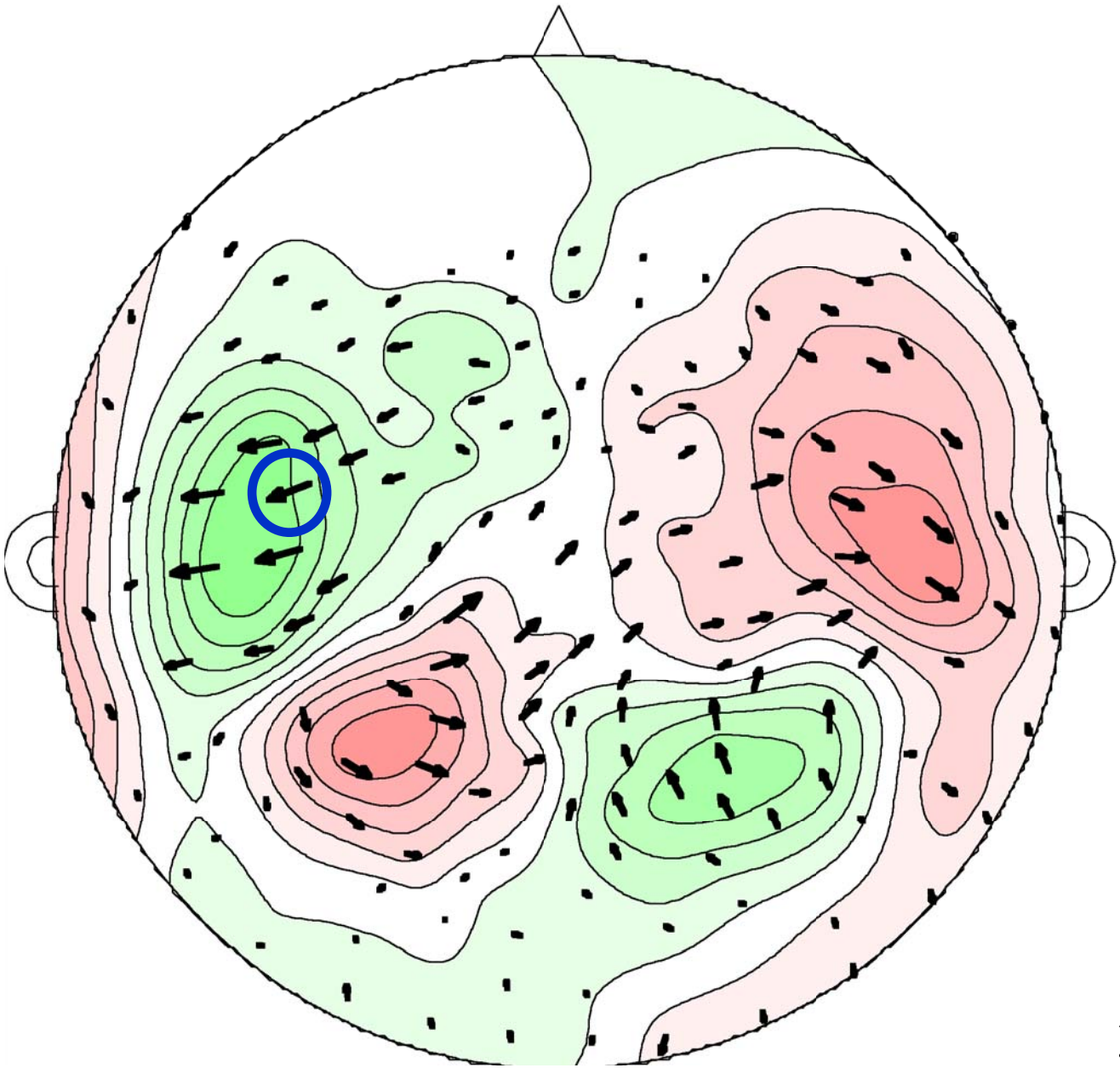
32 Hz Modulation
400 Hz tone carrier
100 trials @ 1 s
(concatenated)



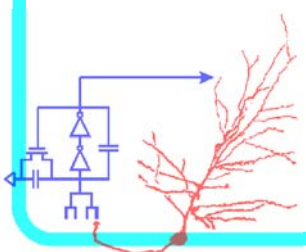


Extremely Precise Phase-Locking: 0.01 Hz
No trial-to-trial jitter

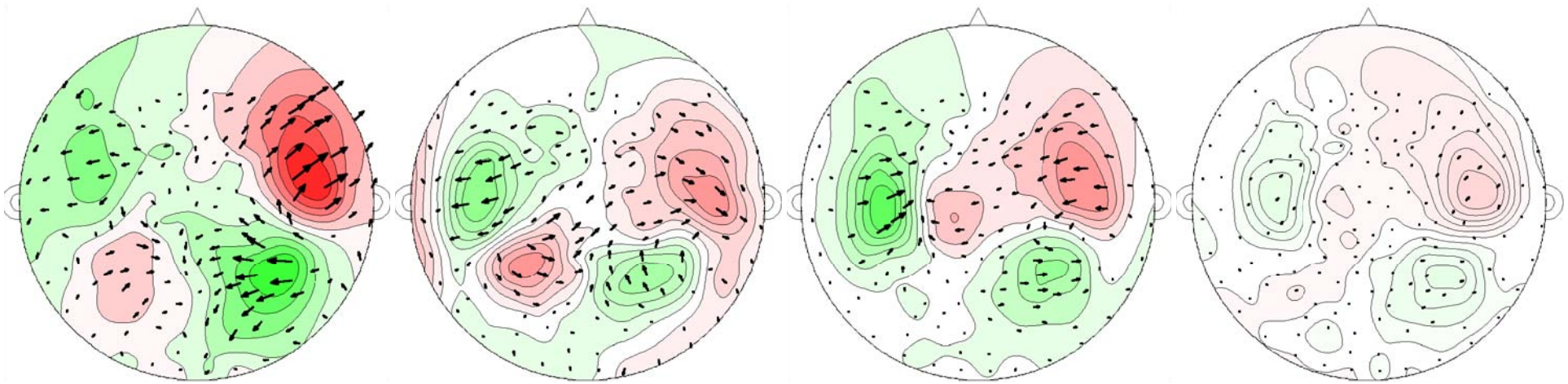
Whole Head Steady State Response



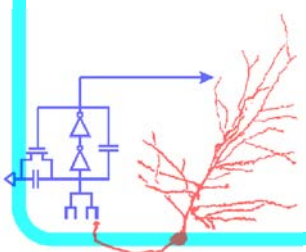
32 Hz



Whole Head Transfer Function

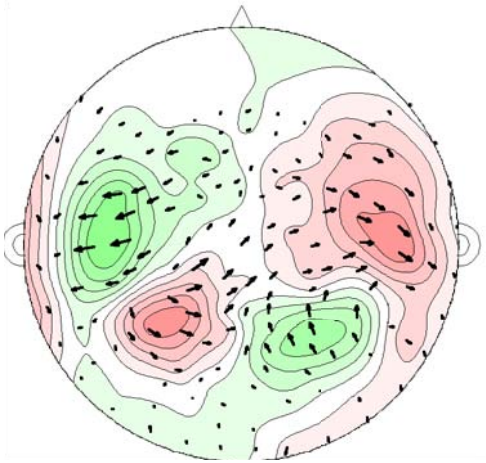


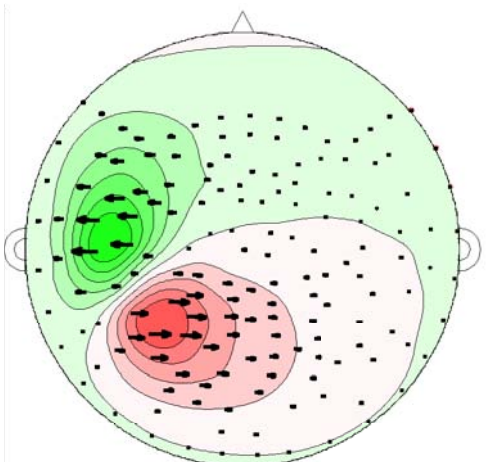
16 Hz 32 Hz 48 Hz 64 Hz

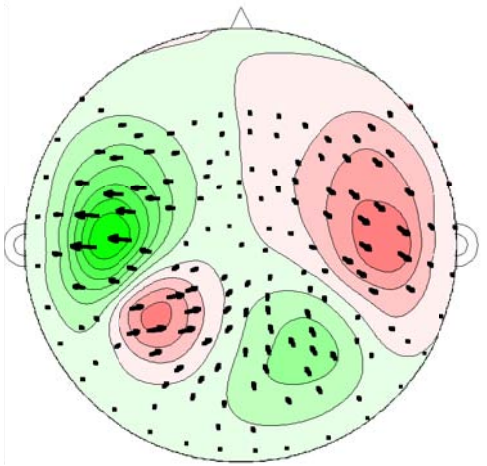


Data Reduction via Equivalent Dipoles

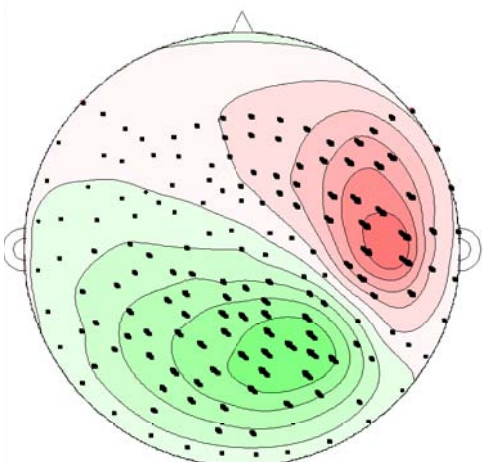
Raw Data







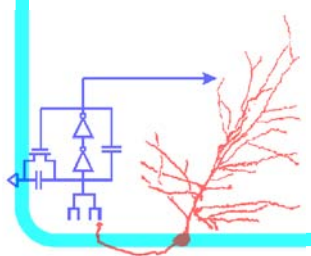
Two Dipole Fit



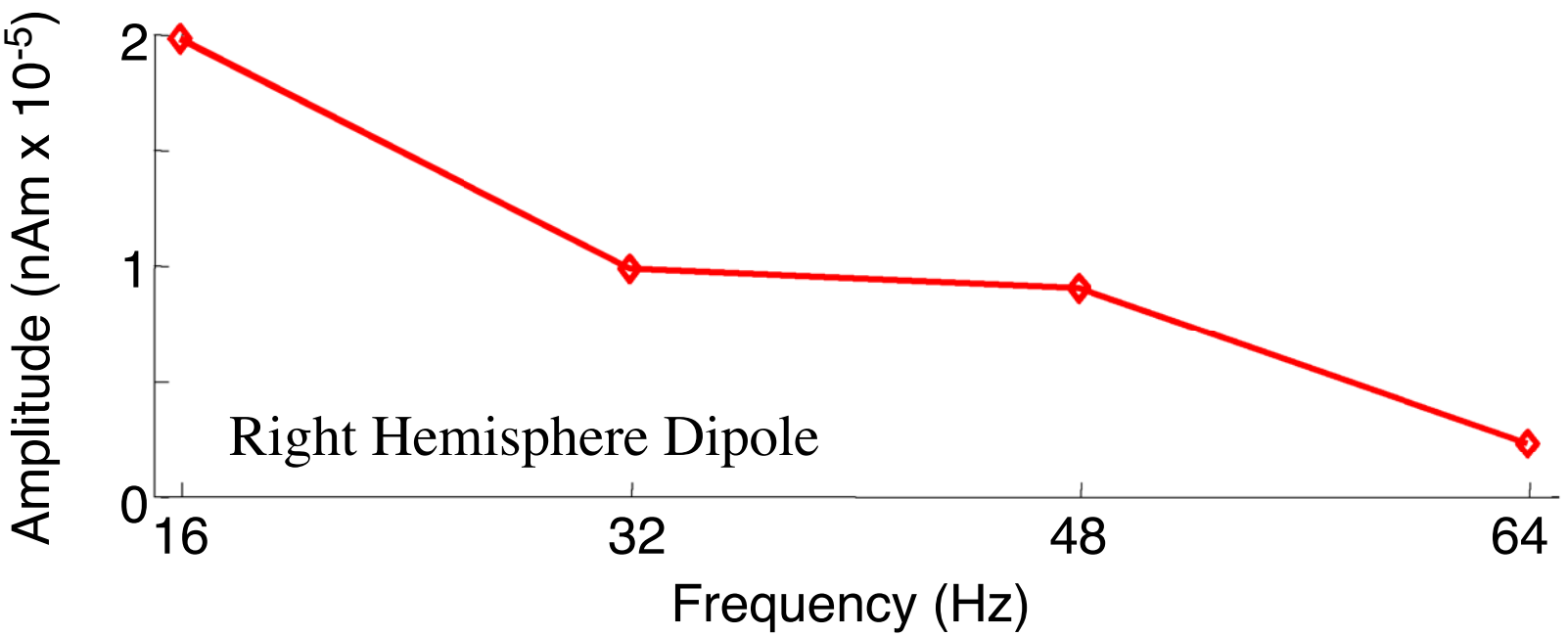
Left Dipole

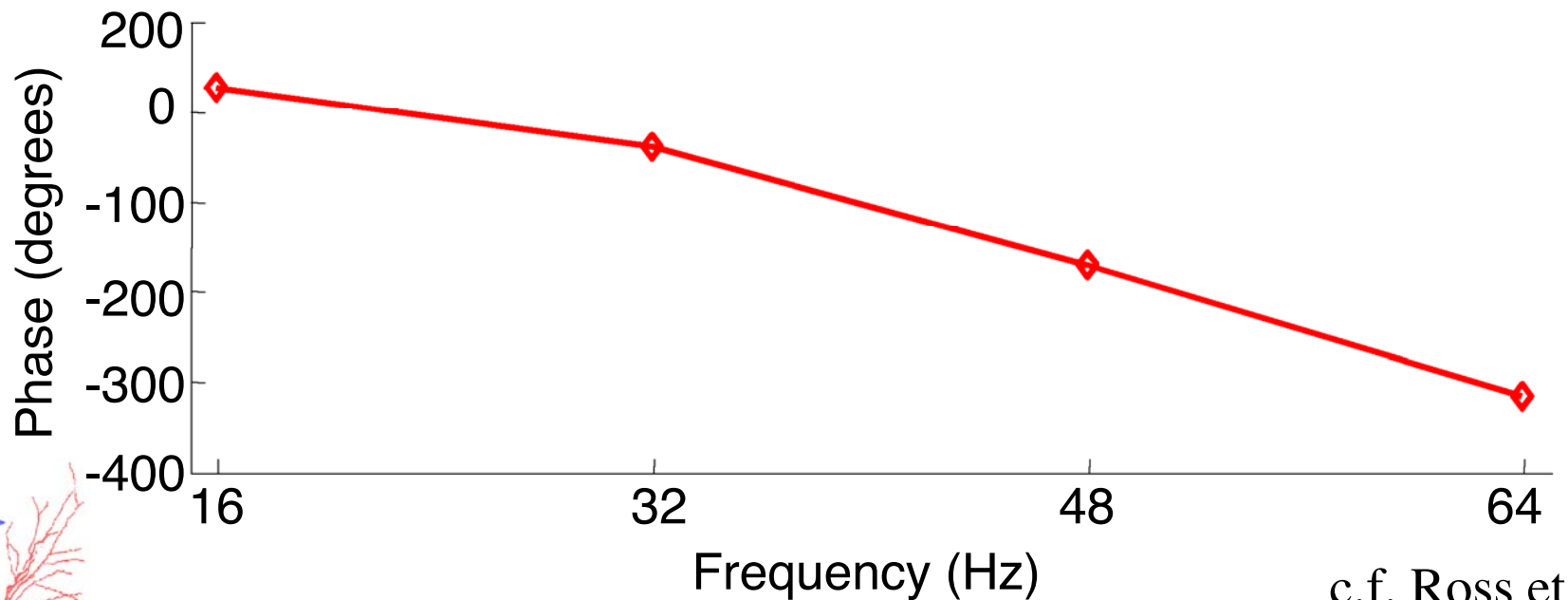
Right Dipole

Dipoles are Complex



Equivalent Dipole Transfer Function

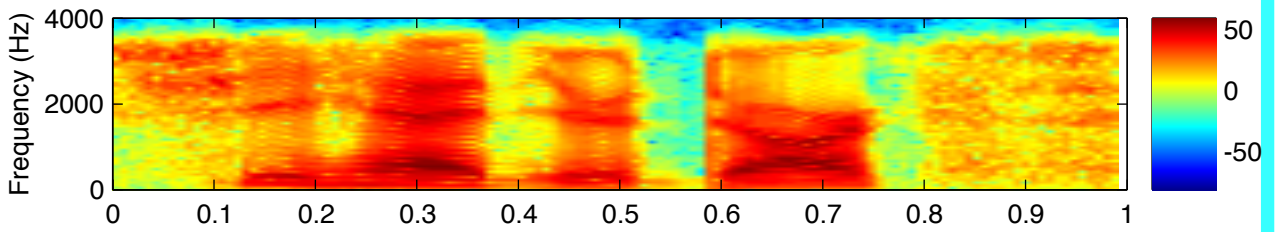




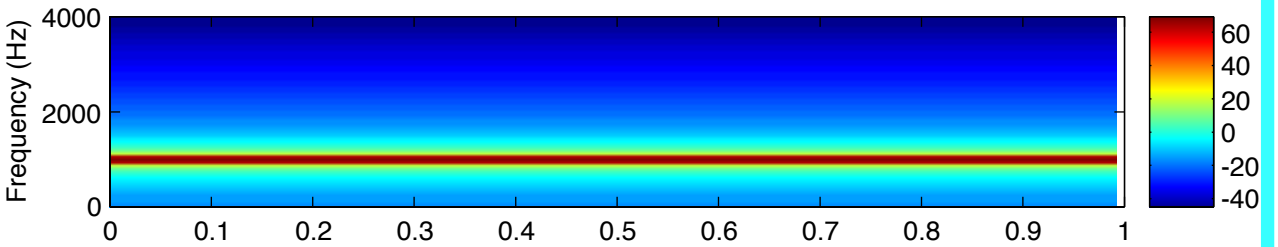
c.f. Ross et al. (2000)

The Dilemma of Complex Stimuli

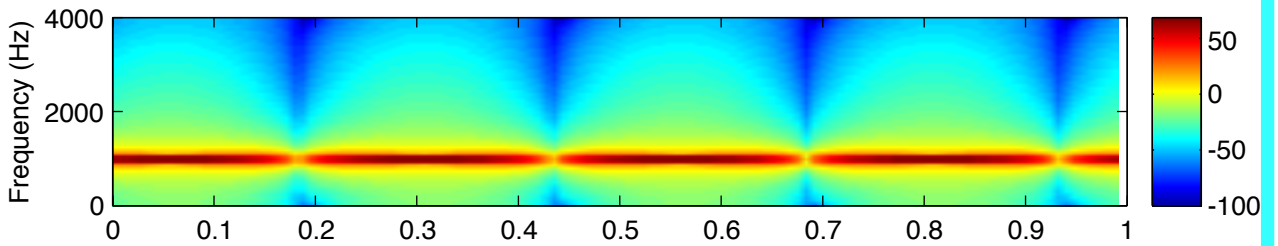
Speech



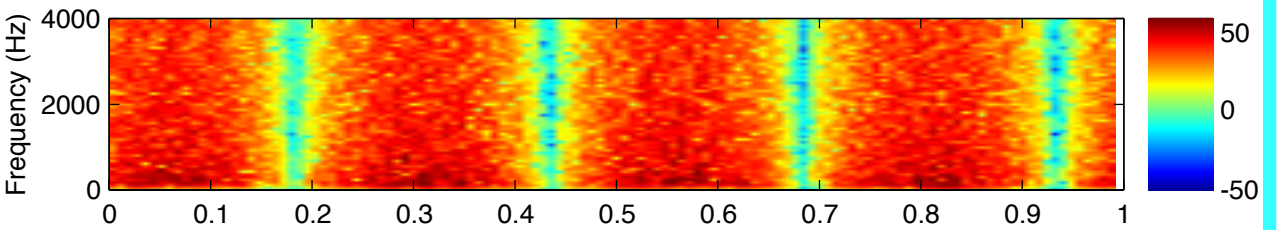
Pure Tone

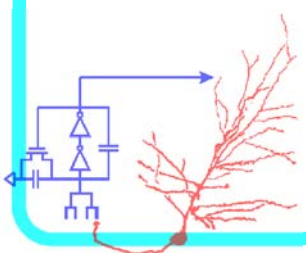


Modulated Pure Tone



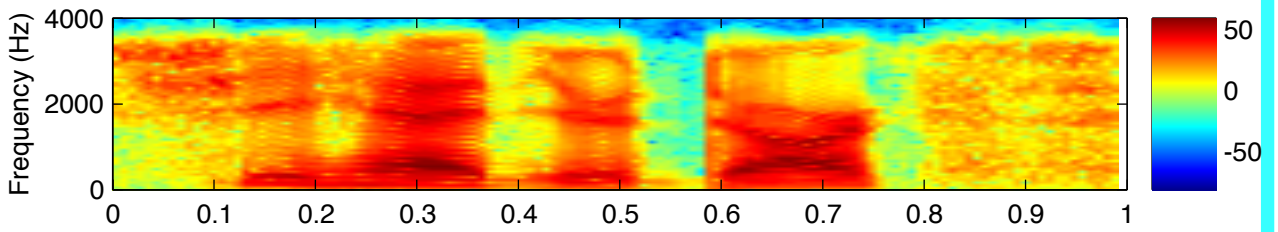
Modulated Broadband Noise



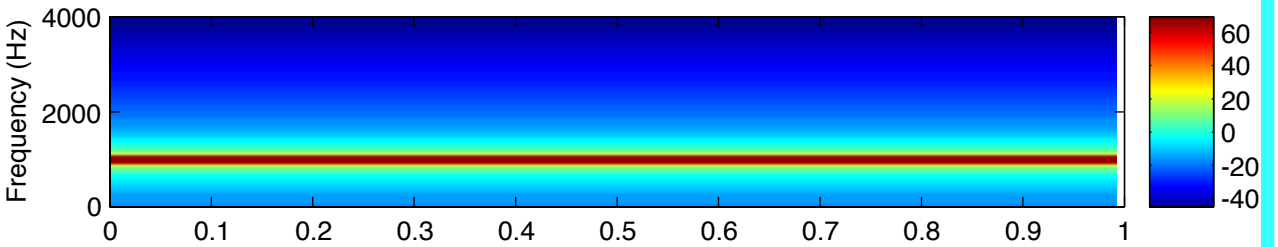


The Dilemma of Complex Stimuli

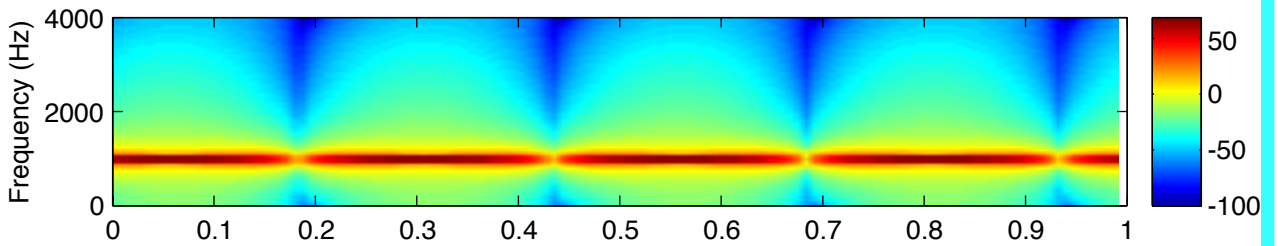
Speech



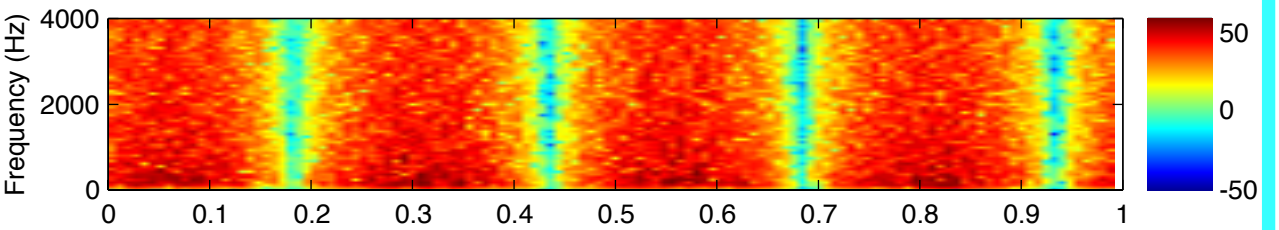
Pure Tone



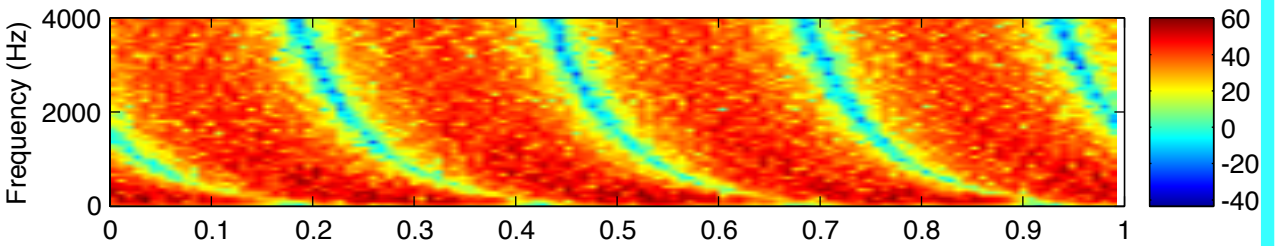
Modulated Pure Tone

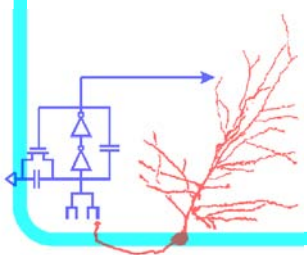


Modulated Broadband Noise

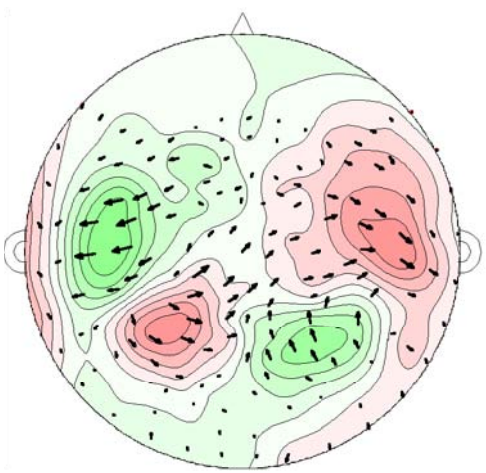


Auditory Ripple

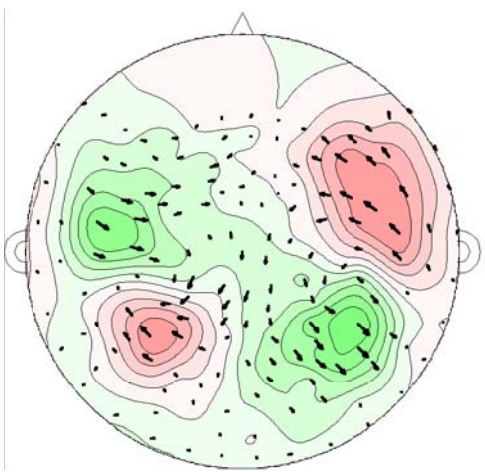




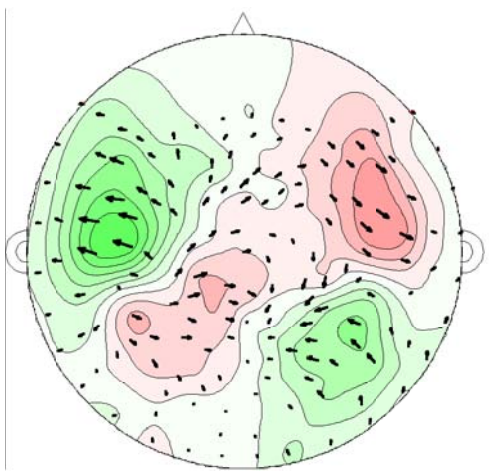
SSR as Function of Bandwidth



Tone

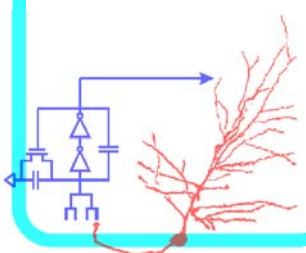


1/3 Octave Noise

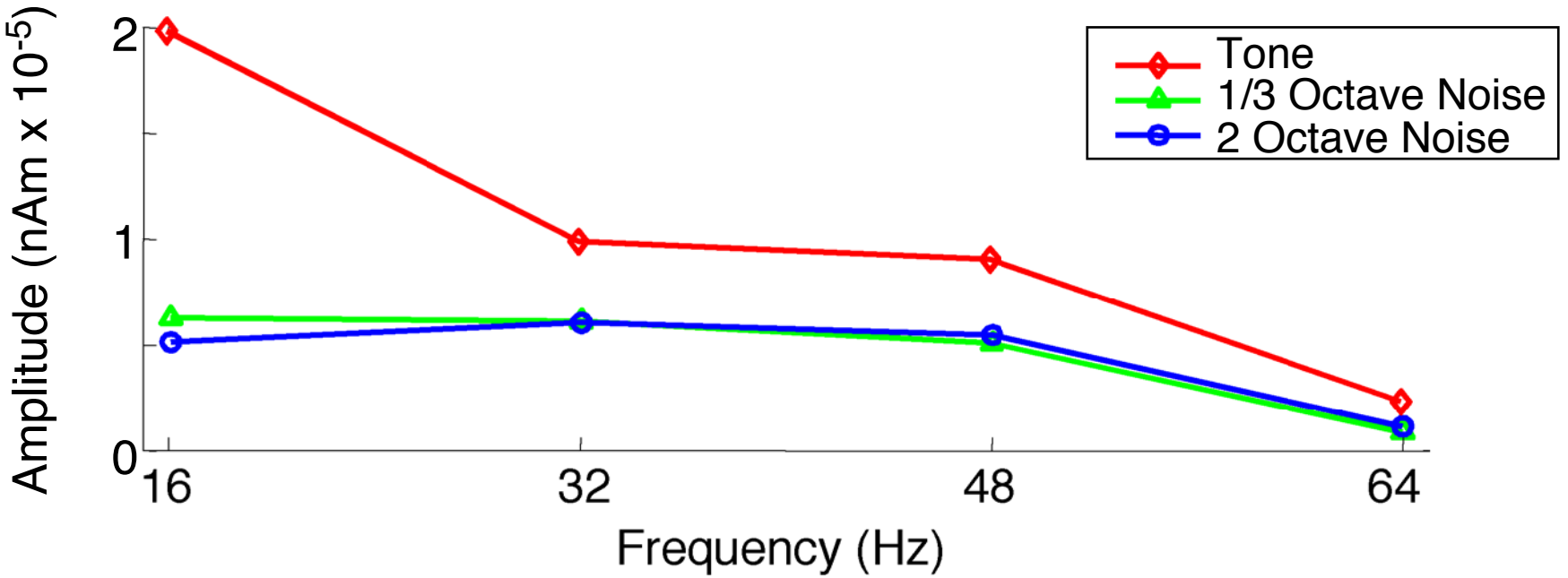


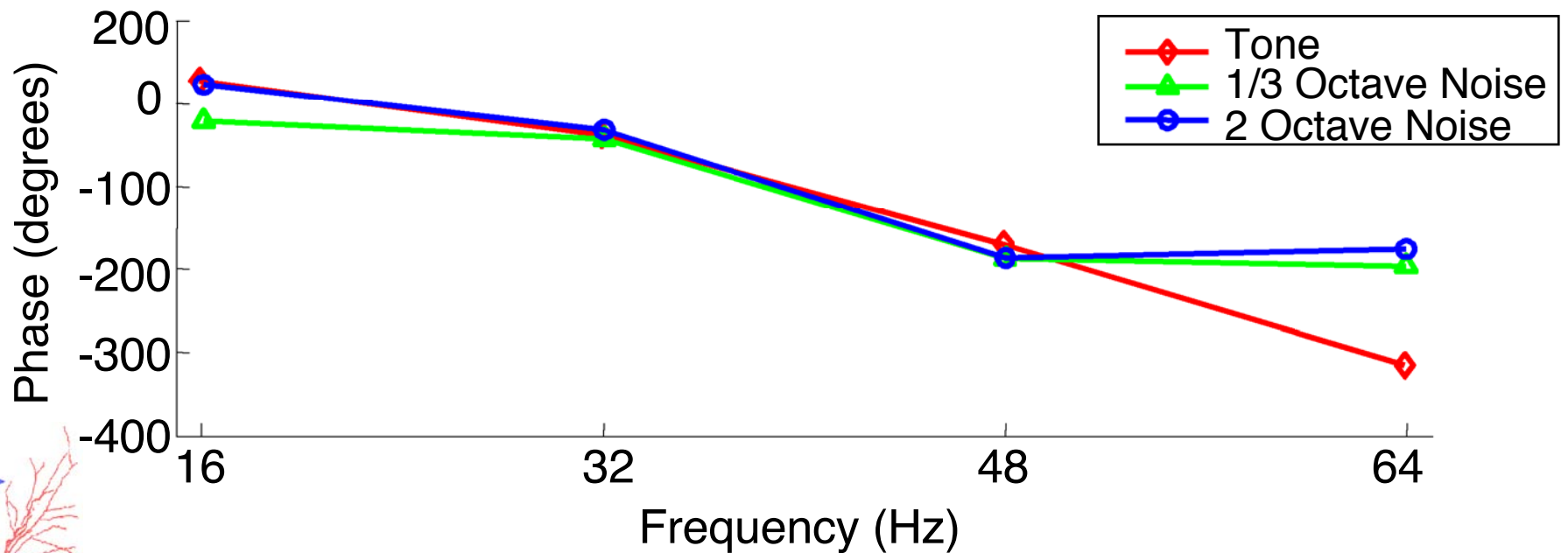
2 Octave Noise

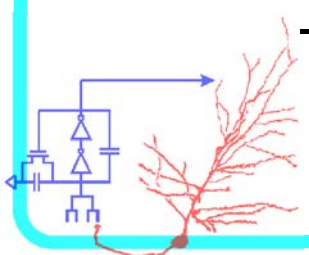
32 Hz Modulation



Multiple Transfer Functions







Stimuli Revisited

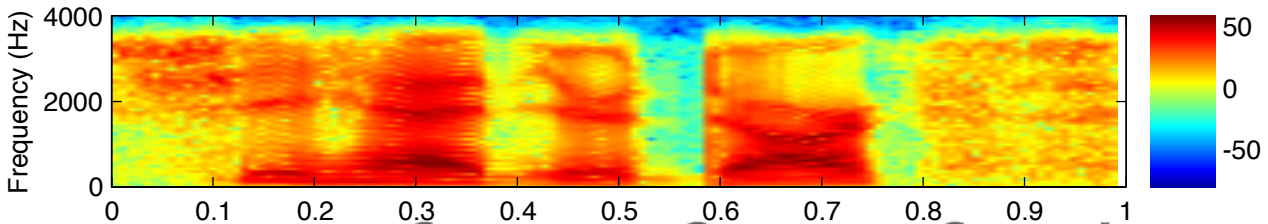
- Multiple Bandwidths: 0 to 5 octaves
- Low Modulation Frequencies: 2 to 32 Hz

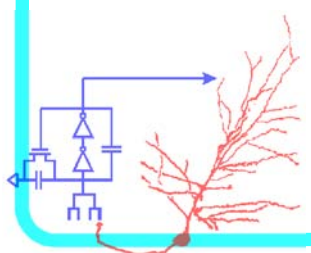
  Natural Sounds (e.g. speech)

  Intracranial Recordings from Human Auditory Cortex find peaks at 4-8 Hz in Liégeois-Chauvel et al. (2004).

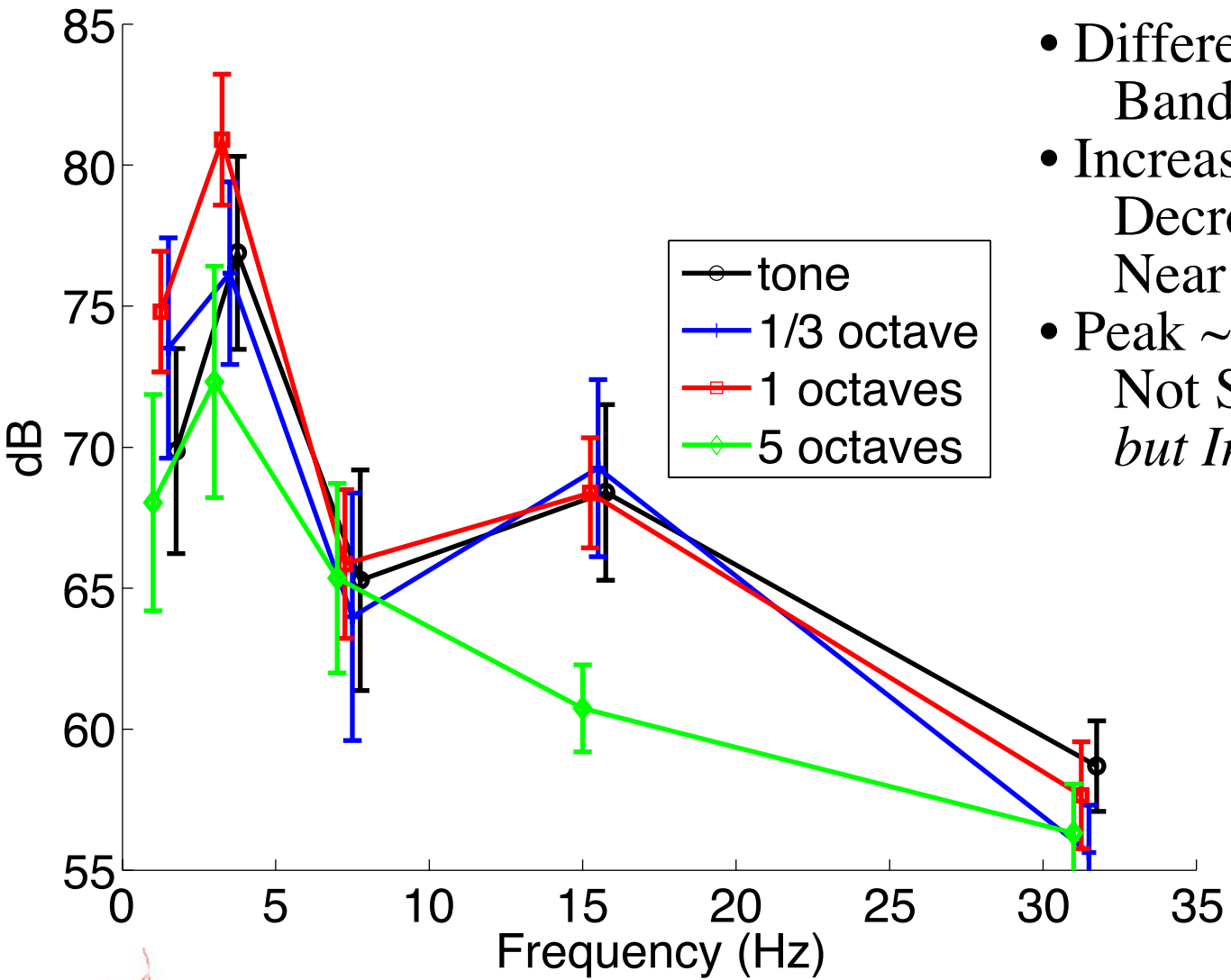
- SSR vs. "Continuous Onsets"?

  Evidence of significant (~30%) linearity to ***envelope of speech*** from Ahissar et al. (2001).



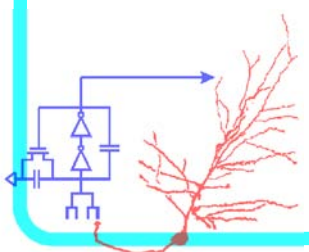


Averaged Transfer Functions



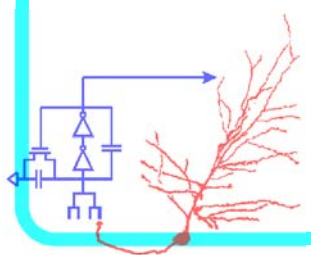
- Differences between Bandwidths Not Significant
- Increasing Response at Decreasing Frequencies Near Significance
- Peak ~4 Hz Not Significant *but Intriguing*

5 Subjects



Still To Do

- More Subjects (beat down variability)
- Simultaneous Two-Dipole Fits
- Fit only to channels of Significant Response:
  e.g. F-test, Rayleigh test, phase-weighted tests
- Reduce Variance due to dipole depth
  Shallow Magnitude/Depth trade off
- Bootstrap confidence intervals within subjects

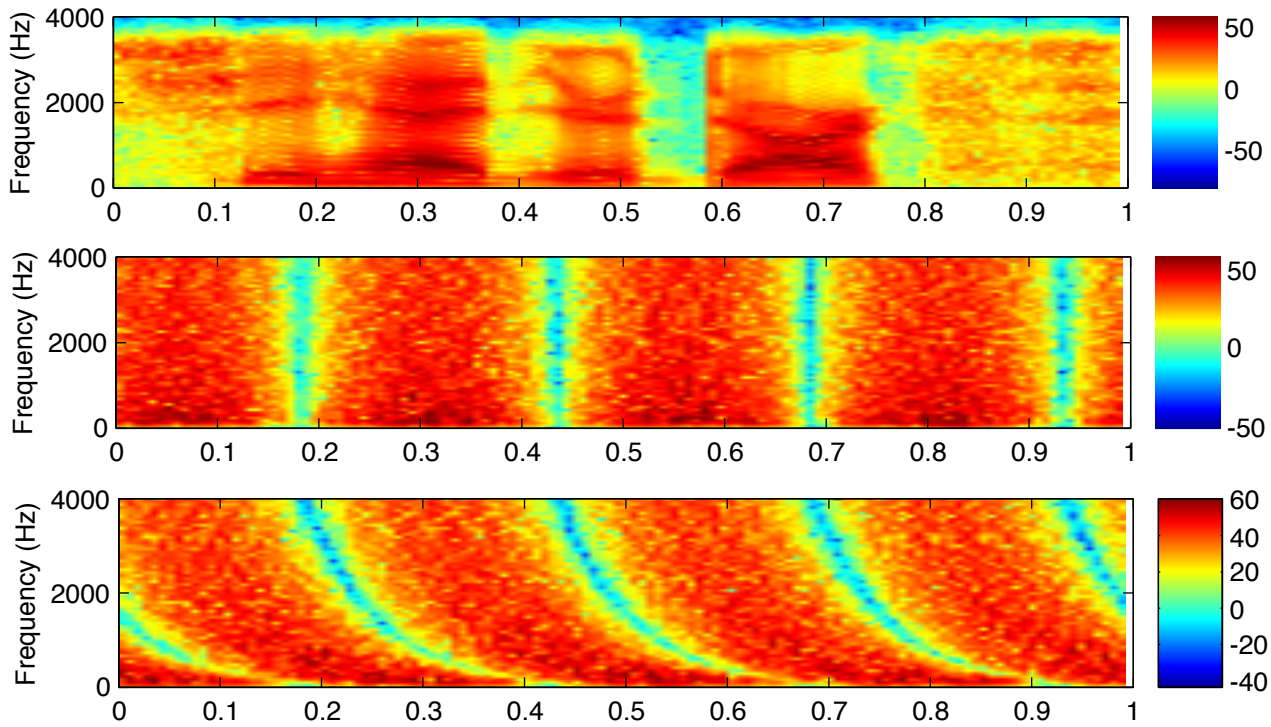


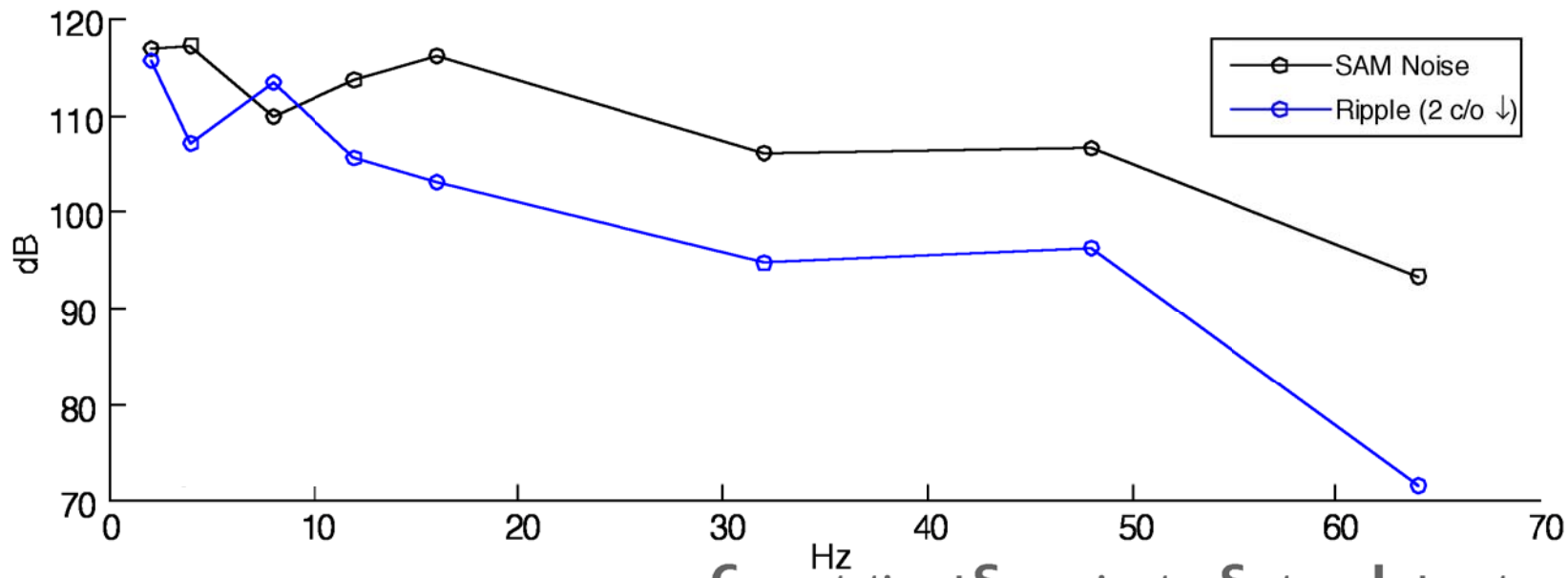
Next on "To Do" List

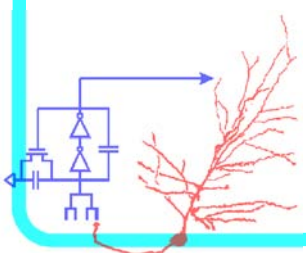
Speech

Modulated Broadband Noise

Auditory Ripple

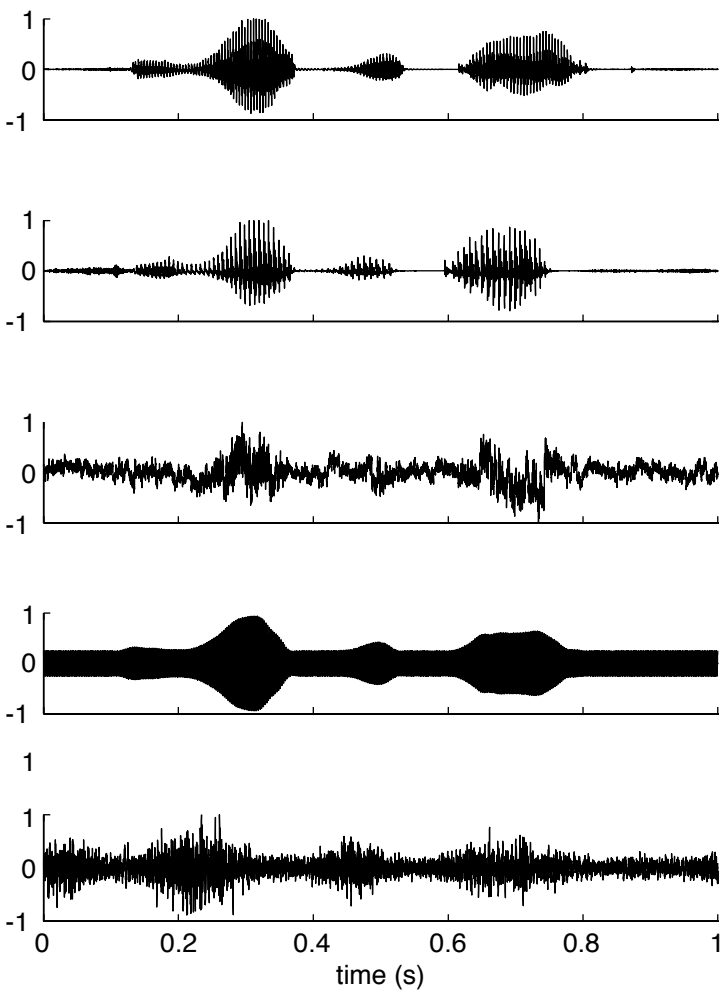




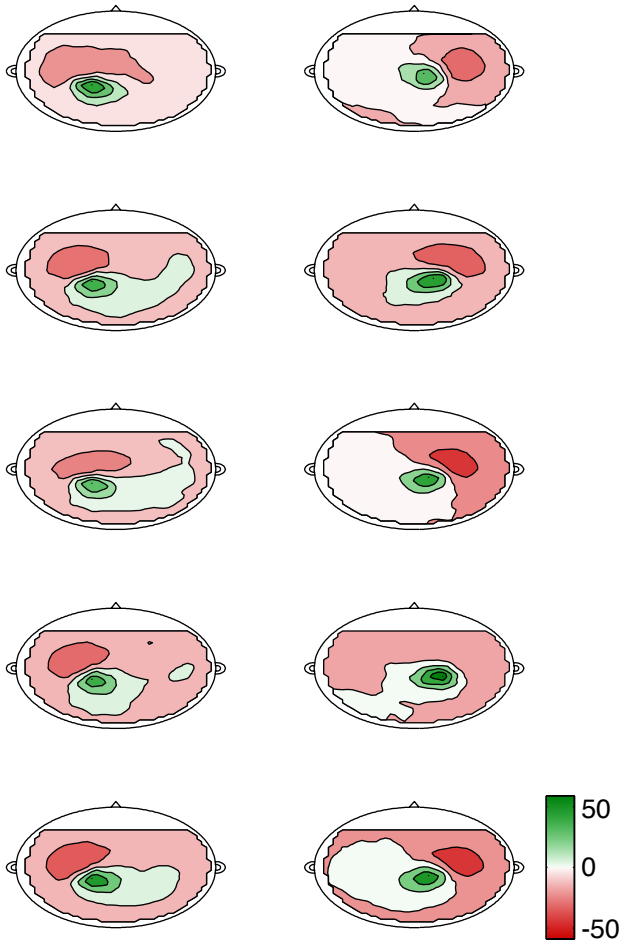


Related Project: Speech + ICA

Speech & Speech-like Stimuli

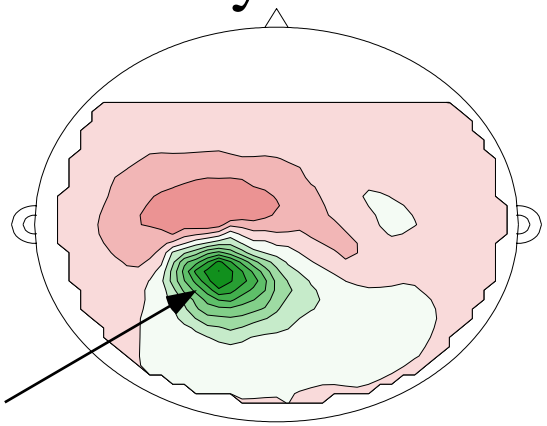


Auditory Independent Component Responses

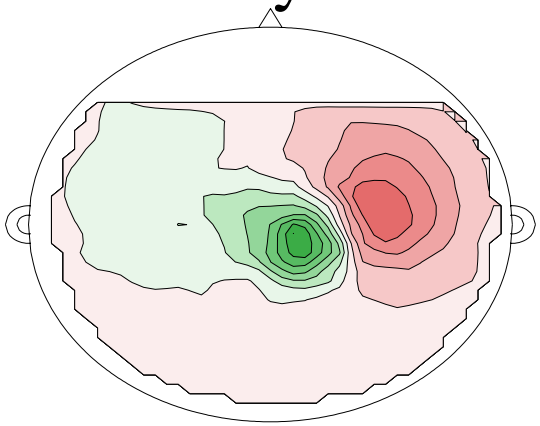


Independent Component Analysis

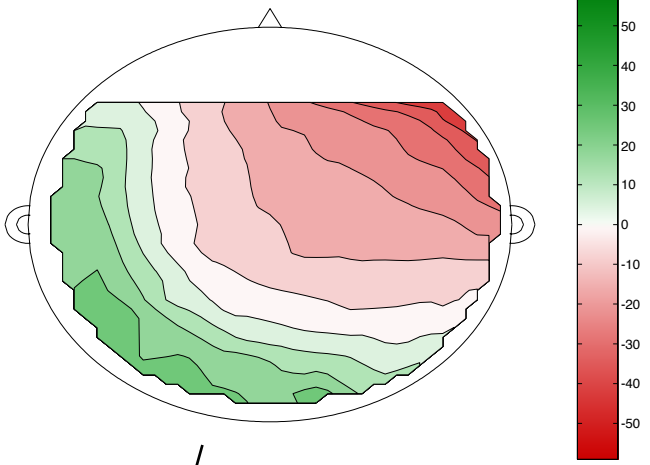
Left
Auditory Cortex



Right
Auditory Cortex



Heartbeat

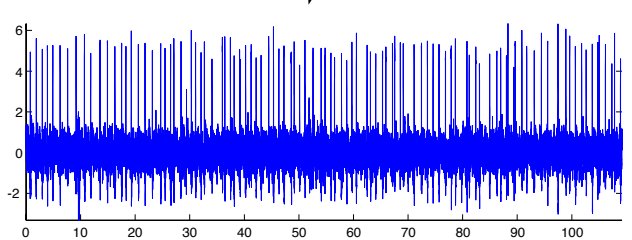


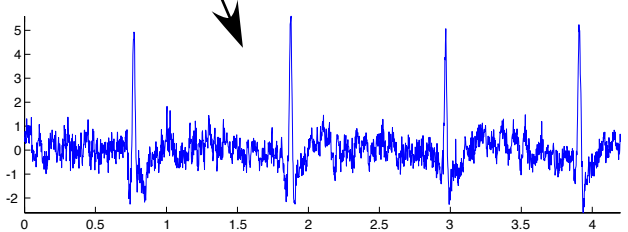
ICA finds:

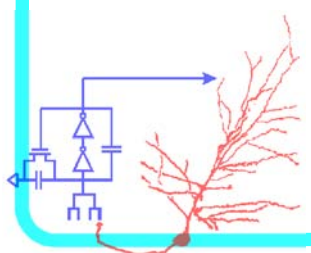
Independent Neural
Sources in *Auditory* areas

Independent Neural
Sources in *non-Auditory* areas

Independent non-Neural Sources

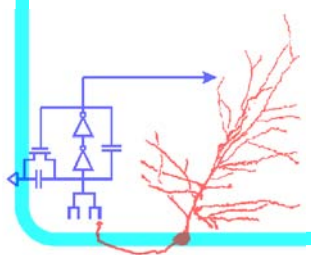






Summary

- Whole Head SSR
  - –> Spatial Phase Coherence
  - –> Complex Dipole
- Dipole Generated Transfer Functions
  - –> Independent of Bandwidth
  - –> Low Pass (?)
  - –> Low Frequency Peak ?
- SSR Methodology Complementary to Time Based Methods (e.g. Speech with ICA)



Thank You

Noise Reduction