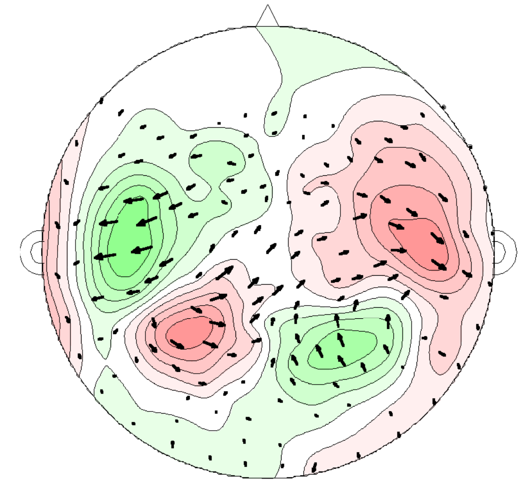
Neural Coding of Multiple Stimulus Features in Auditory Cortex



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Luo, H., Y. Wang, D. Poeppel & J. Z. Simon (2006), J. Neurophysiology

Introduction

- Magnetoencephalography (MEG) as a tool of Non-Invasive Auditory Physiology
- Neural Encoding of Simple Modulations
- Neural Encoding of Independent Modulation Pairs (AM & FM)

Magnetoencephalography (MEG)

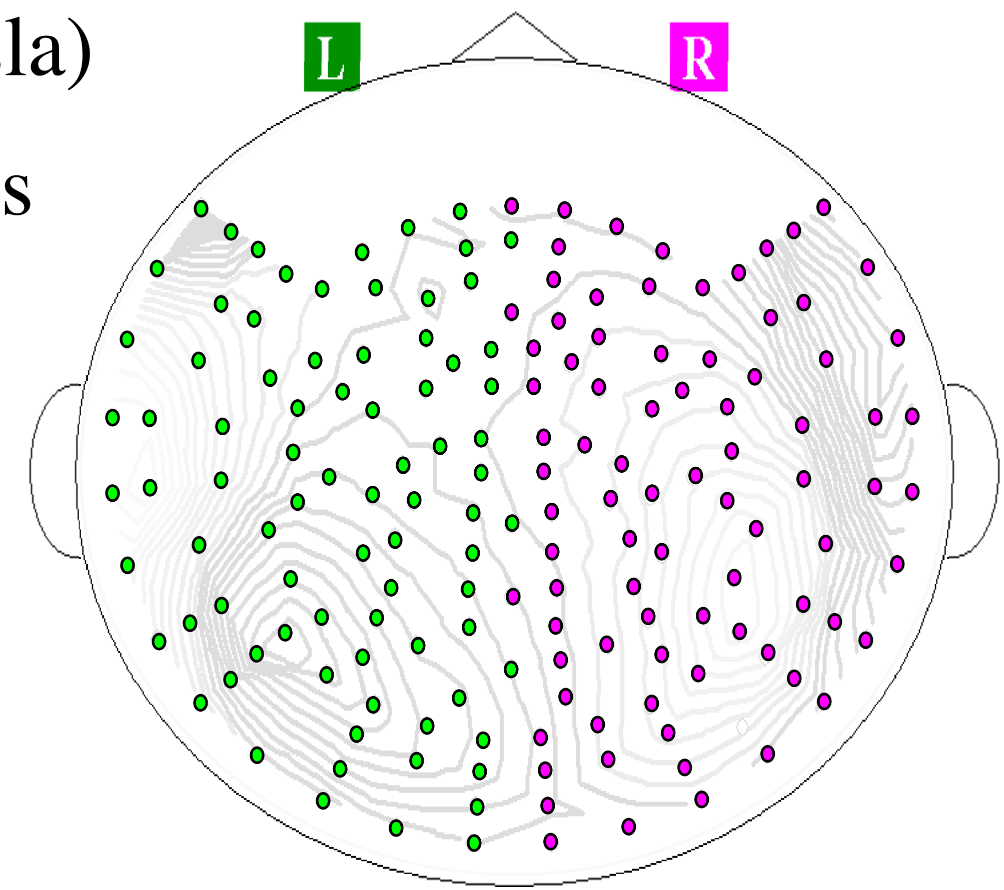
- Non-invasive, Passive, Silent
- Simultaneous Whole-Head Recording (~200 sensors)
- Sensitivity

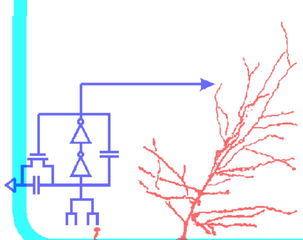
  high: ~100 fT (10^{-13} Tesla)

  low: ~10^4 – ~10^6 neurons
- Temporal Resolution: ~1 ms
- Spatial Resolution

  coarse: ~1 cm

  ambiguous





Neural Activity = Neural Current

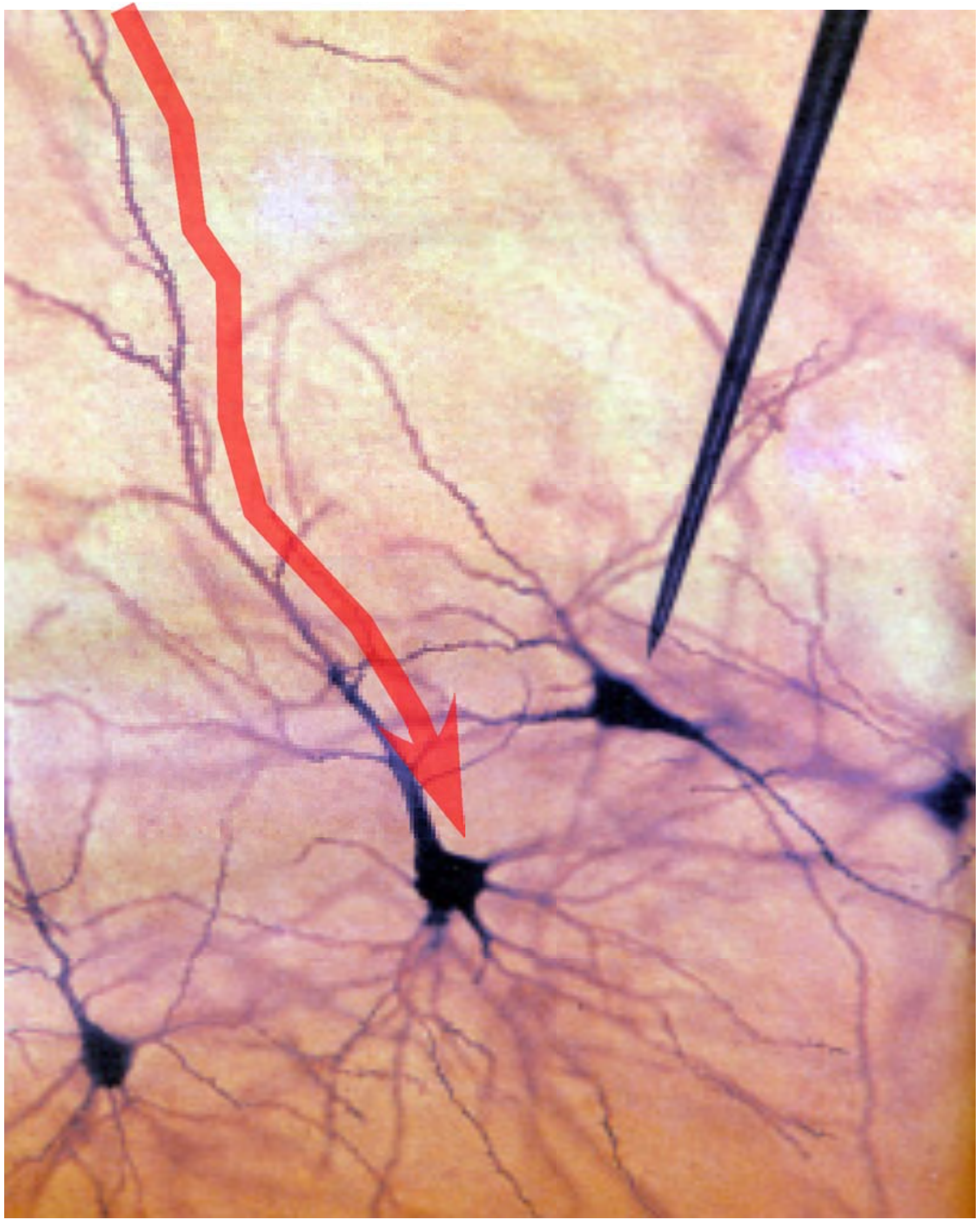
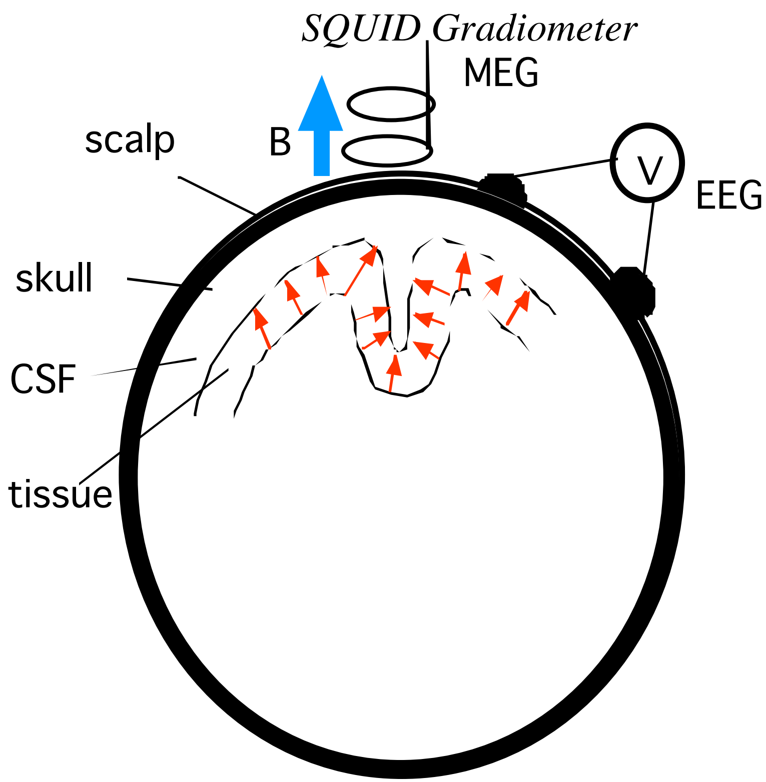
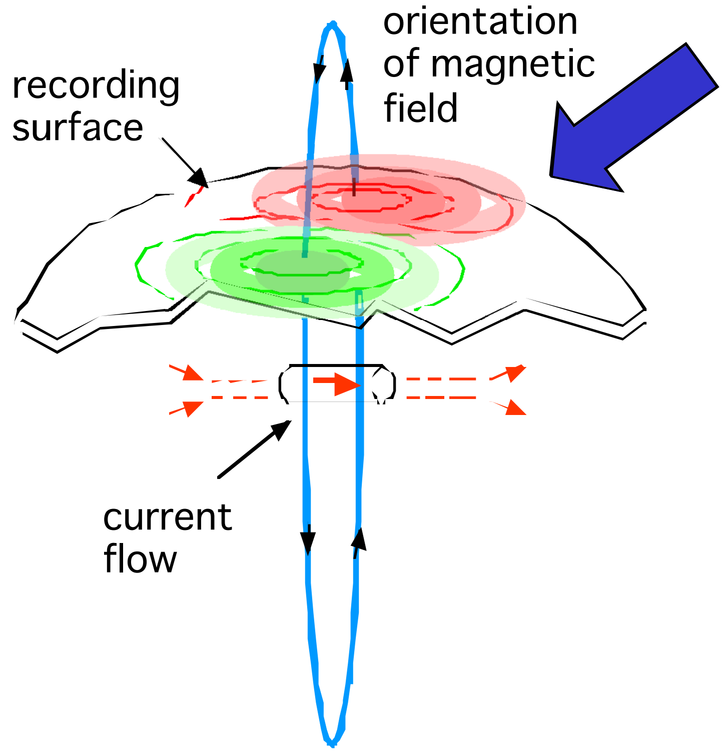


Photo by Fritz Goro

MEG Magnetic Signal



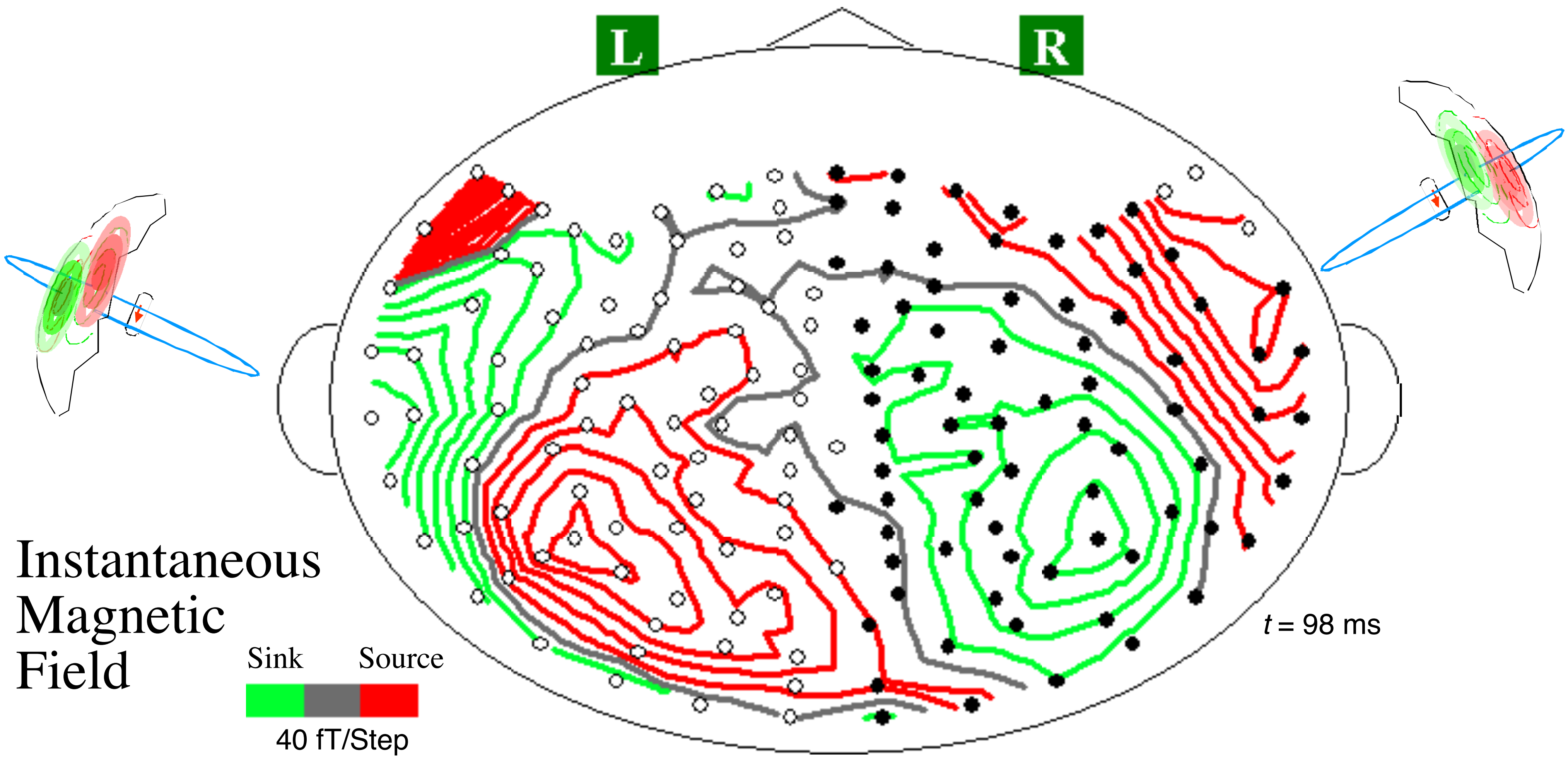
Magnetic Dipolar Field (Projection)



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

MEG Response

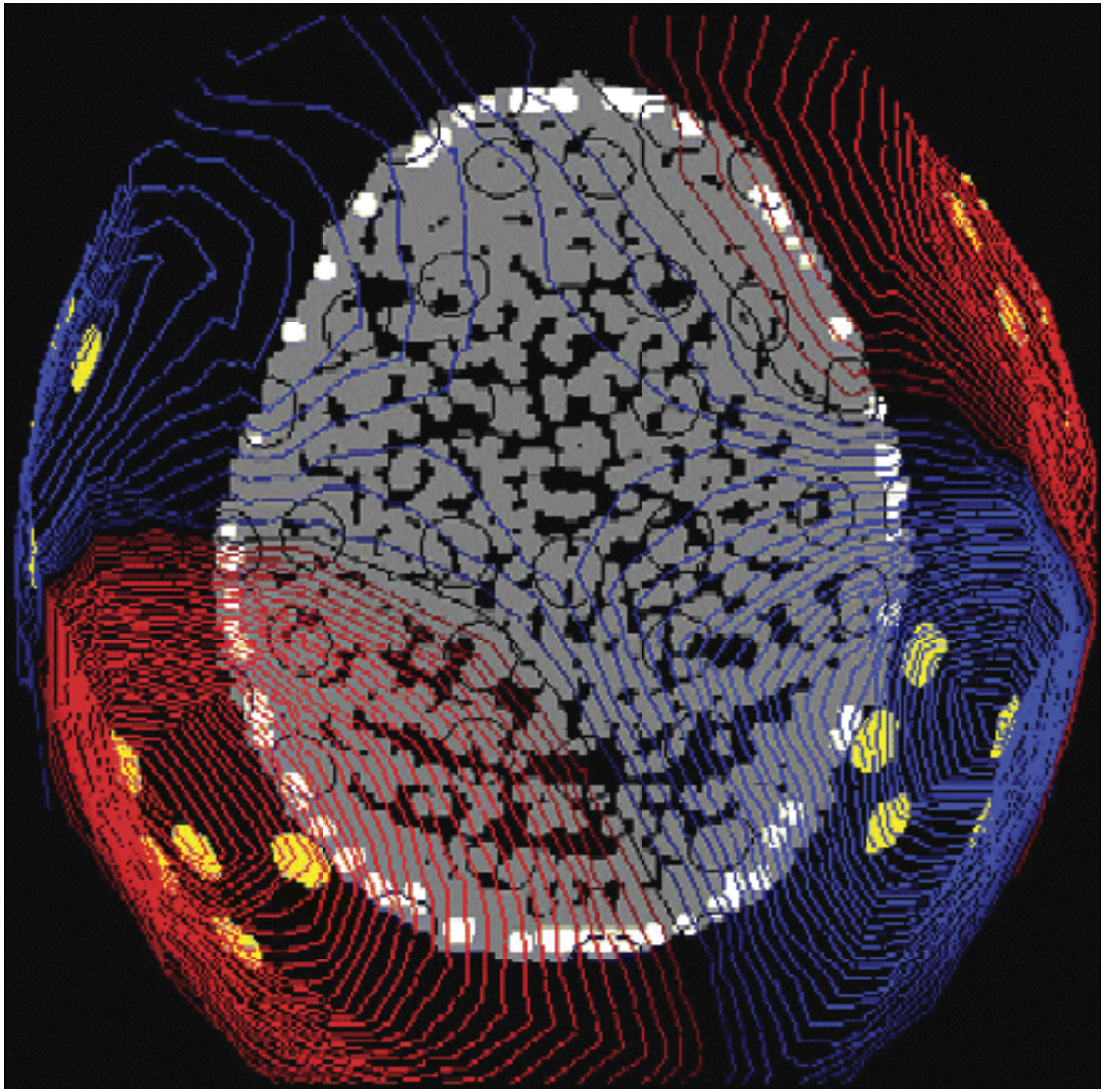
Flattened Isofield Contour Map



Instantaneous Magnetic Field

MEG Response

3-D Isofield Contour Map



Public Relations Moment

Cerebral CORTEX

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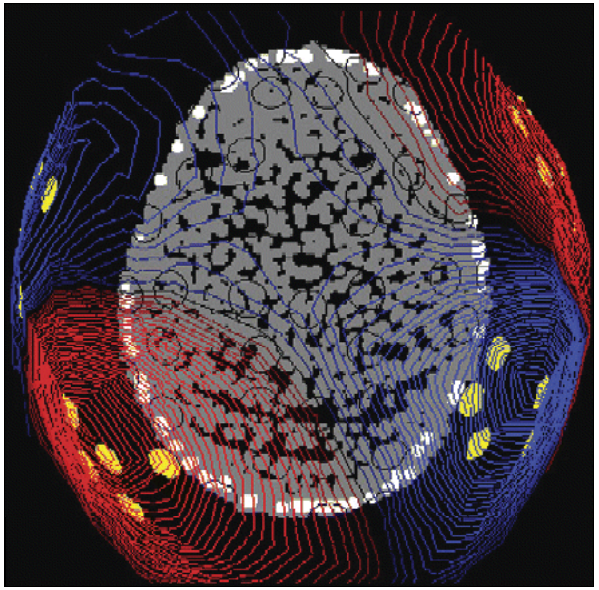
About the Cover



Cover Picture: Axial view of the cortically-generated magnetic field of a human listener, measured using whole-head magnetoencephalography (MEG), at a single moment in time. Isofield contours in red (respectively, blue) indicate the strength of outward (inward) magnetic flux; the digitized scalp surface is in gray. For each hemisphere, a magnetic dipole-like pattern is centered over temporal cortex, and the neural generator itself, located in planum temporale, is an inferiorly flowing neuronal electric current. The MEG channels responding most strongly (in the center of each flux area) are designated by filled yellow circles. The acoustic stimulus is a 1 kHz pure tone; time is 100 ms post onset. The image is generated with the MEG160 software (Yokogawa electric corporation, KIT, Japan). See Chait, Poeppel, and Simon, pp. 835–848.

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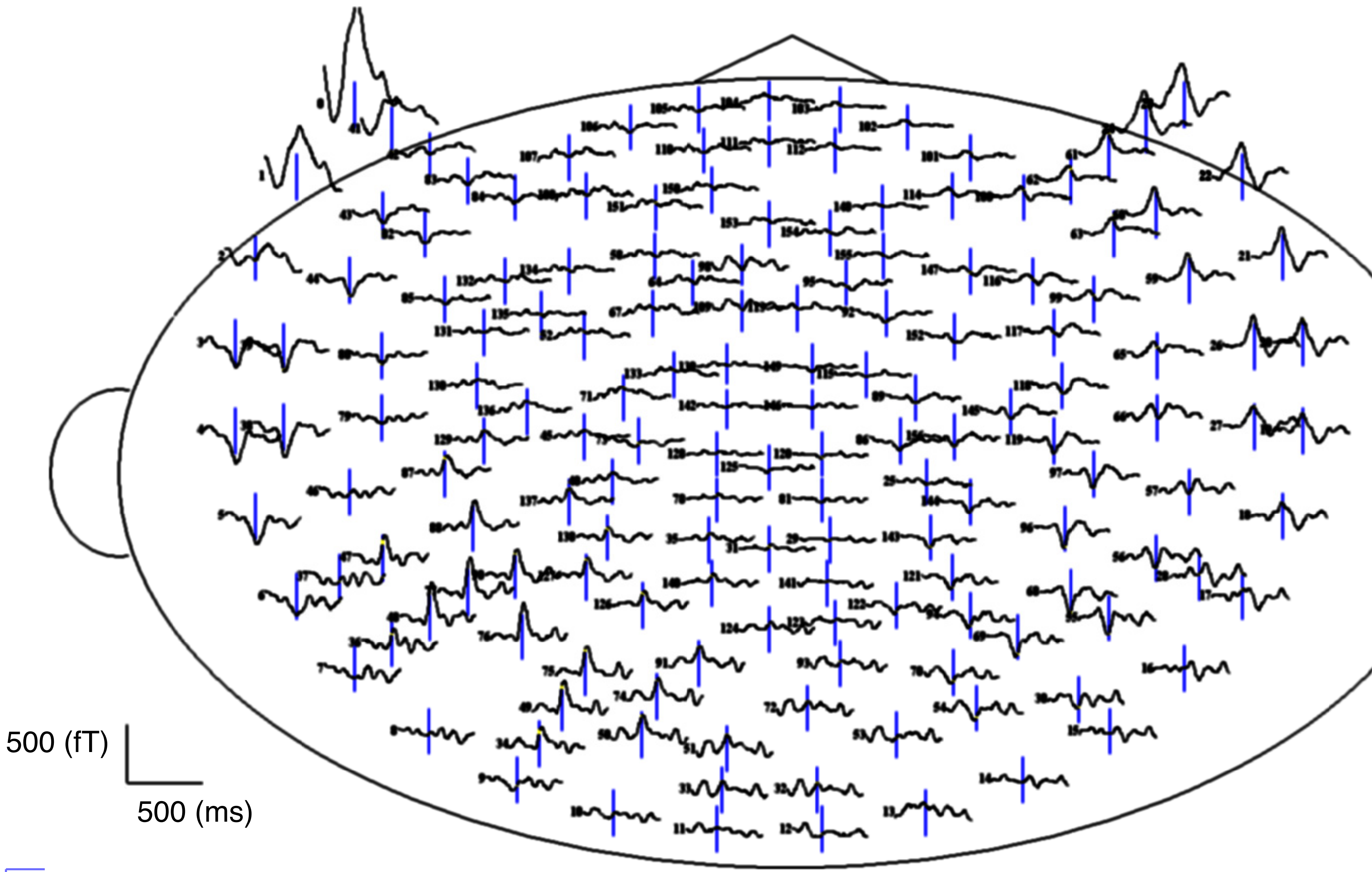
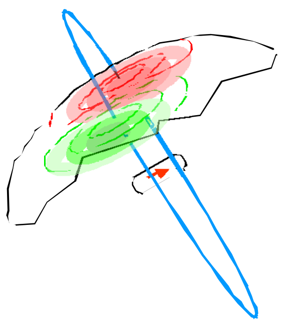
MEG Response

Spatial Map of Time Series



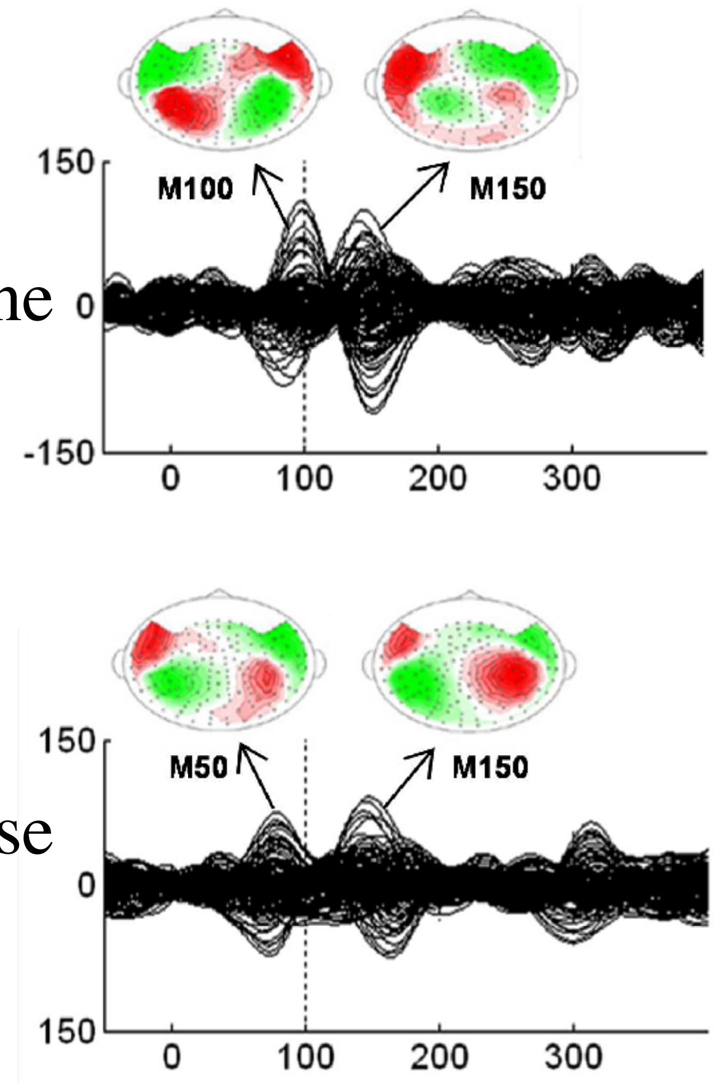
Time Course of MEG Responses

Evoked Responses
MEG Events Time-Locked
to Stimulus Event



Pure Tone

Broadband Noise



MEG as Auditory Physiology Tool

- Advantages of humans over animals
  - Subjects can be rented (by the hour)
  - Subjects can be trained in minutes
  - Better grasp of subjects perceptual space (?)
  - Access to Speech & Language processing (?)
- Advantage of Whole Head Recording
- Disadvantage of Neural Source Localization
  - Coarseness/Ambiguity in Source Location
  - Blindness to Many Kinds of Coding
- Neutral Aspects
  - Neural Source is Dendritic Current (not Spikes)
  - Humans not typical mammals (?)
  - New Technique/Immature Analysis Tools

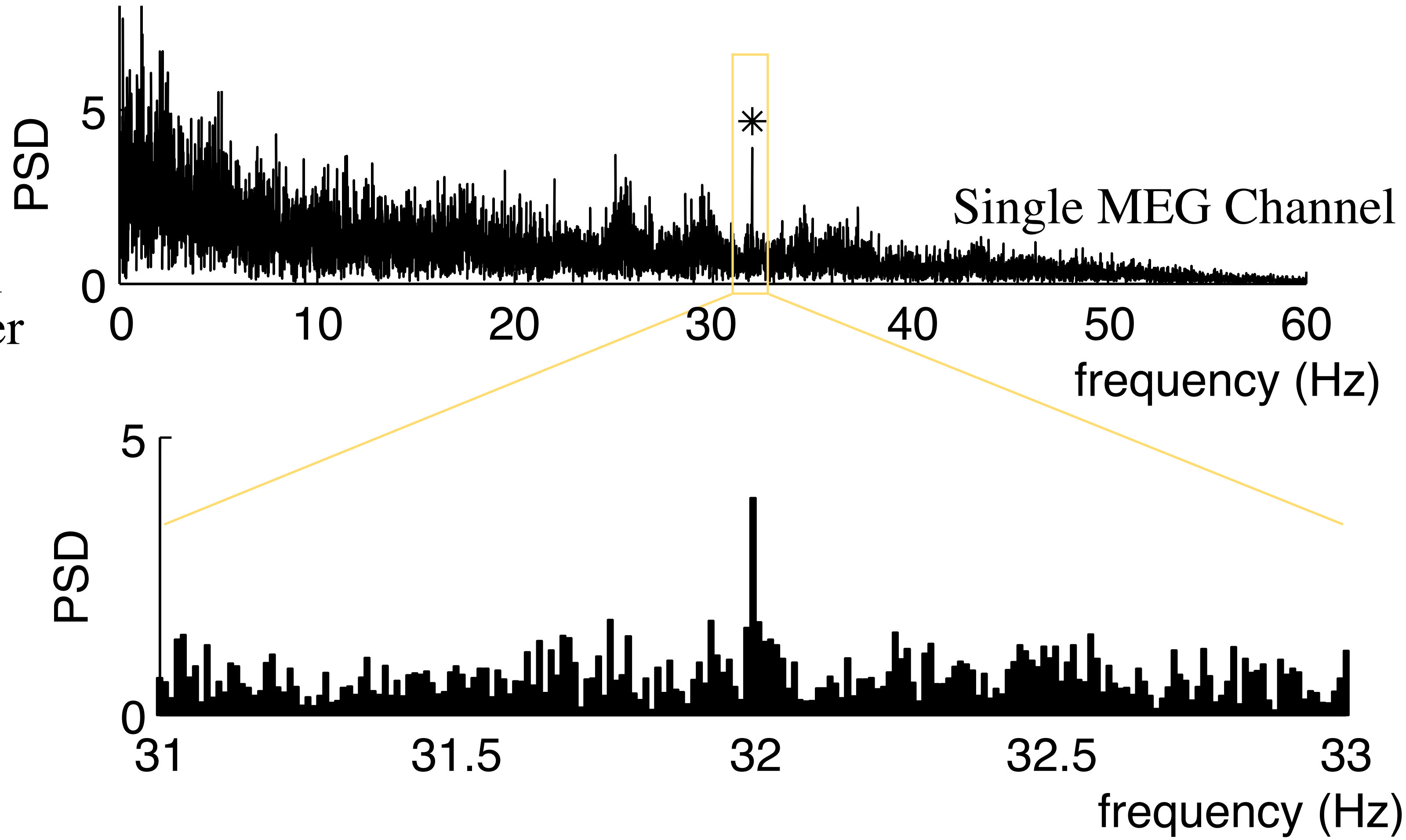
Modulation Encoding

- Simple Modulations ➡ Simple Cortical Encoding
  - Amplitude Modulation coding for slower modulations
  - Rate coding (invisible to MEG) for faster modulations
- Applies to general modulations: AM, FM, other
- Amplitude Modulation coding is easily detectable in Fourier/Spectral domain
  - Spectral Peak at Modulation Frequency

Frequency Response

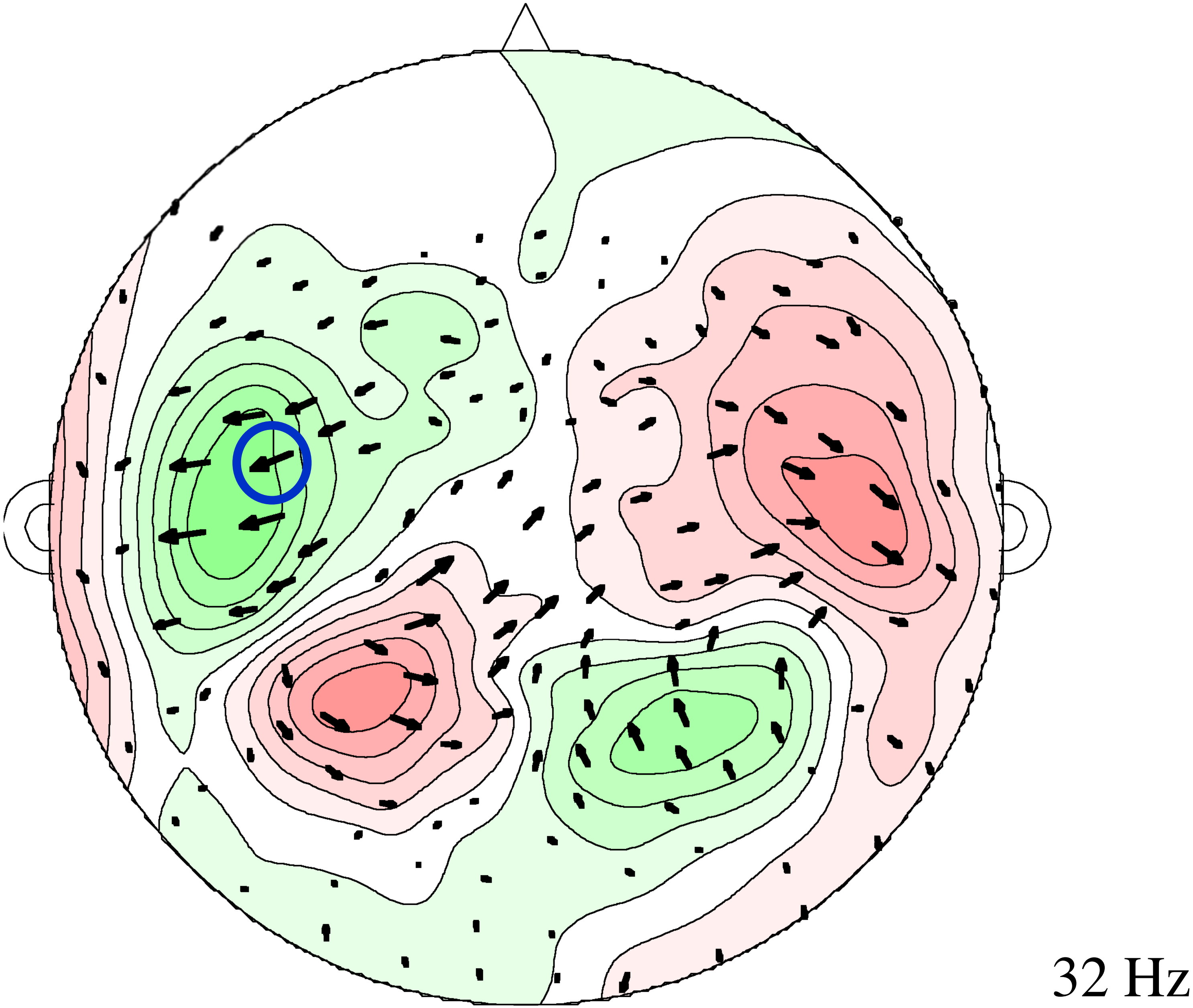
Stimulus Modulated at Single Frequency ➡ ***Steady State Response*** (SSR)

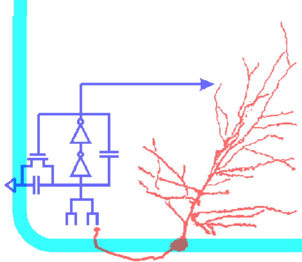
32 Hz Modulation
400 Hz tone carrier
100 trials @ 1 s
(concatenated)



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

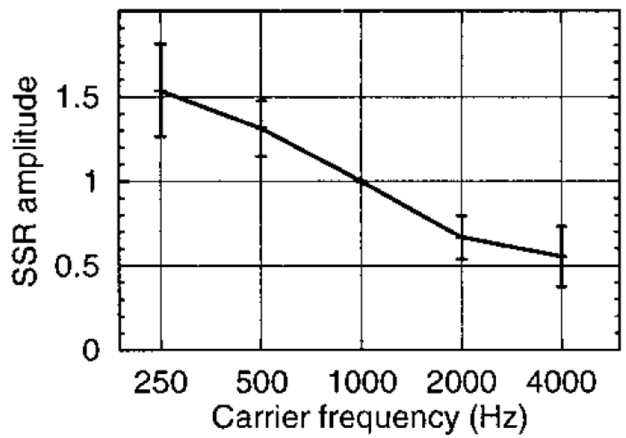
Whole-Head SSR



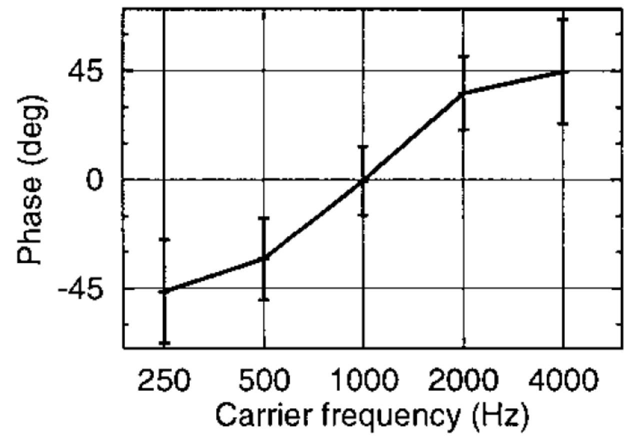


SSR Carrier Dependence

SSR Amplitude



SSR Phase

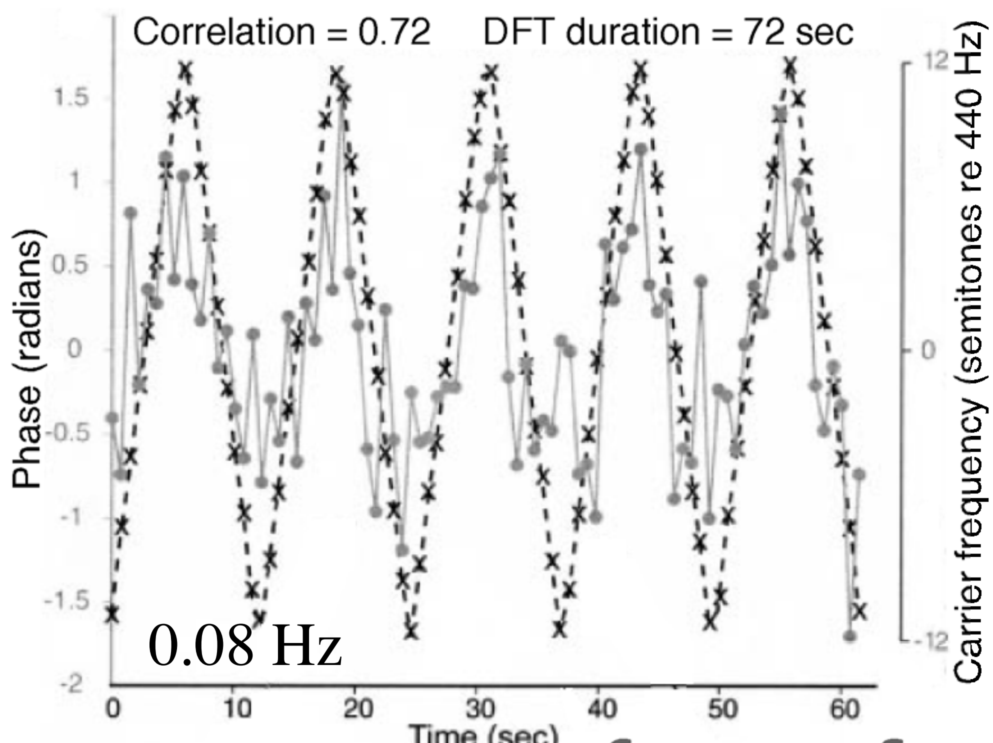


Ross et al. (2000)

SSR Phase Follows Carrier

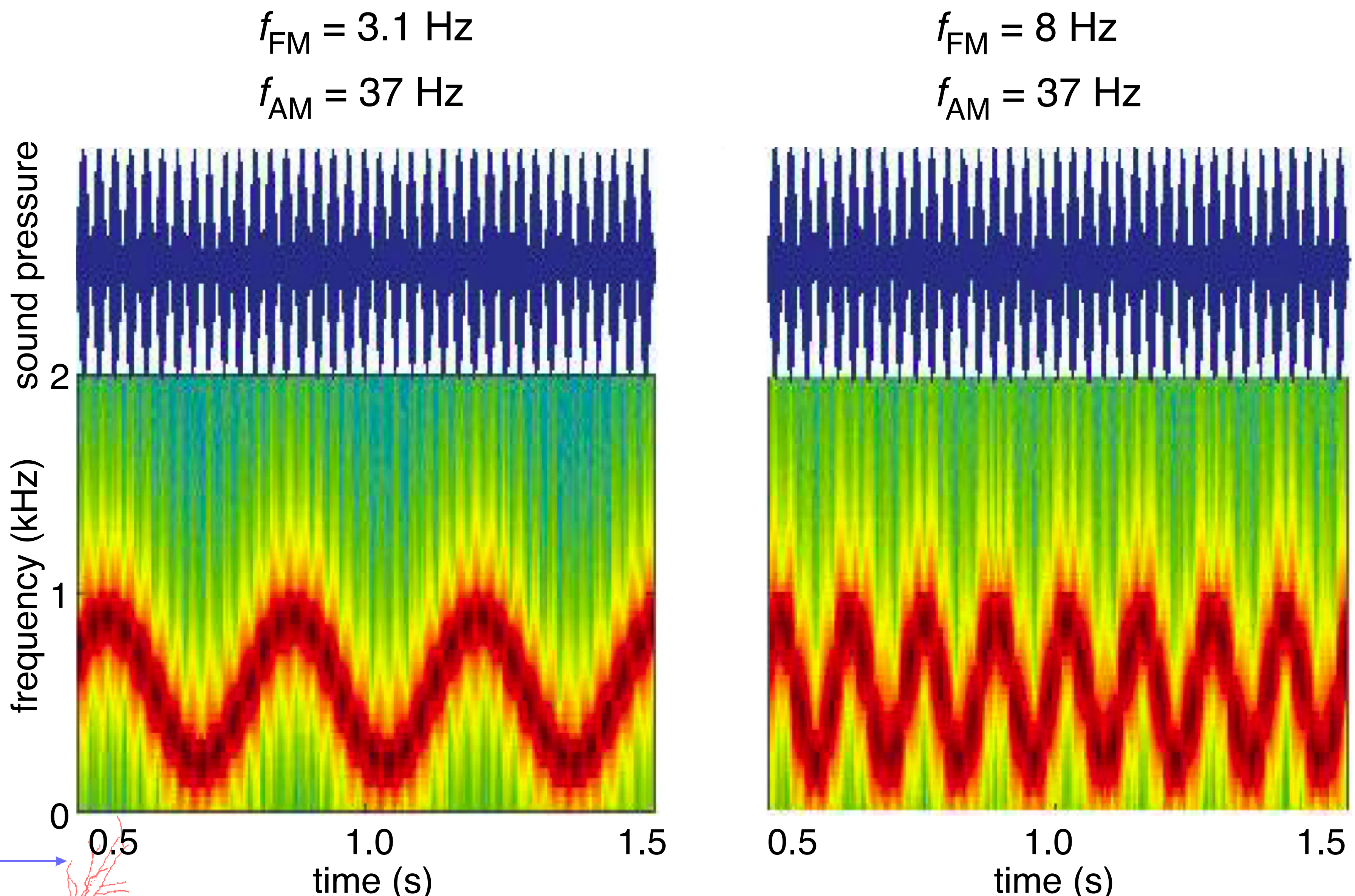
⬇

Phase Modulation Encoding

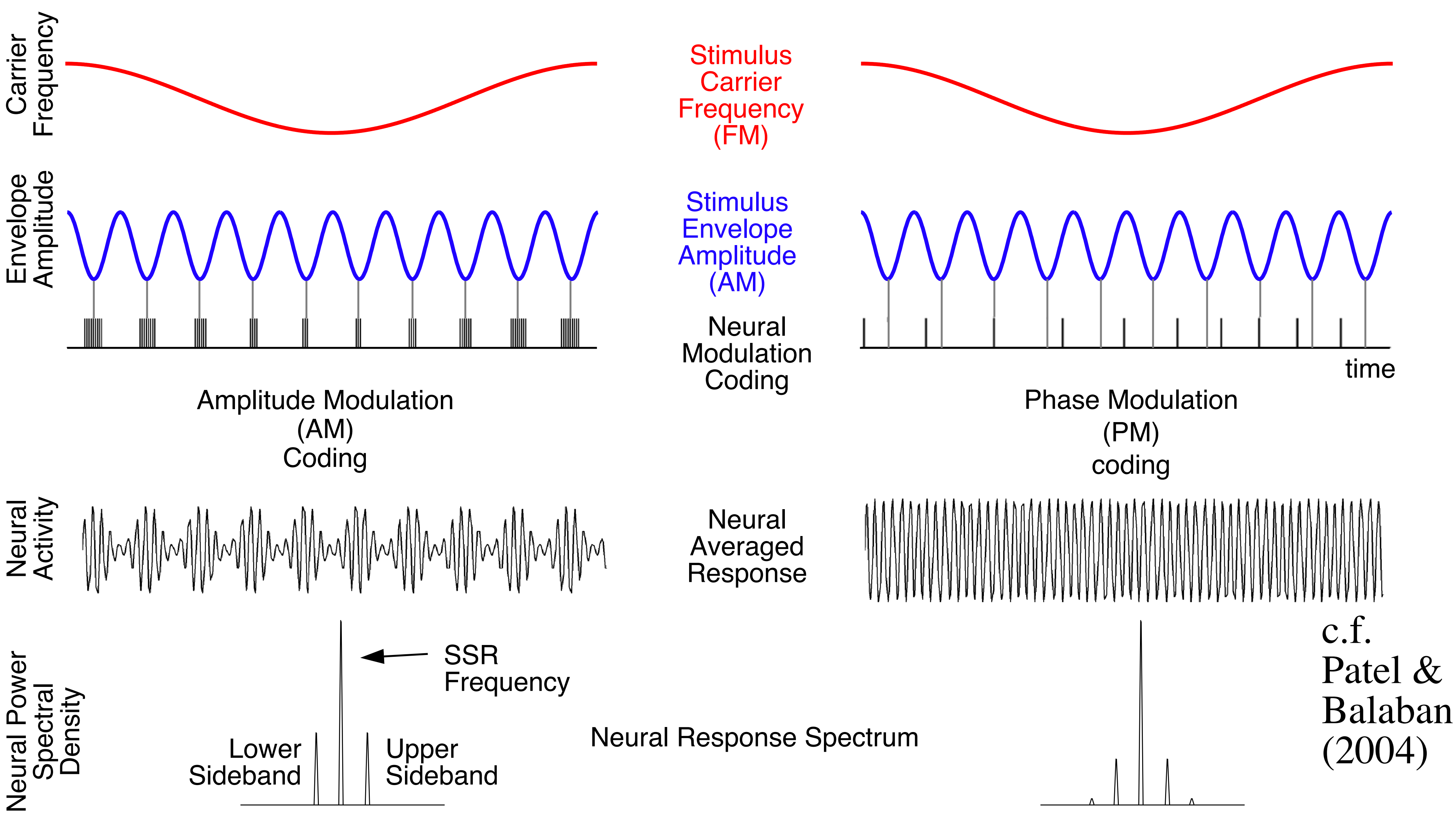


Patel & Balaban (2004)

Sample Dual Modulation Stimuli



Neural Modulation Models



c.f. Patel & Balaban (2004)

$$\alpha = (\varphi_{upper} - \varphi_{SSR}) - (\varphi_{SSR} - \varphi_{lower})$$

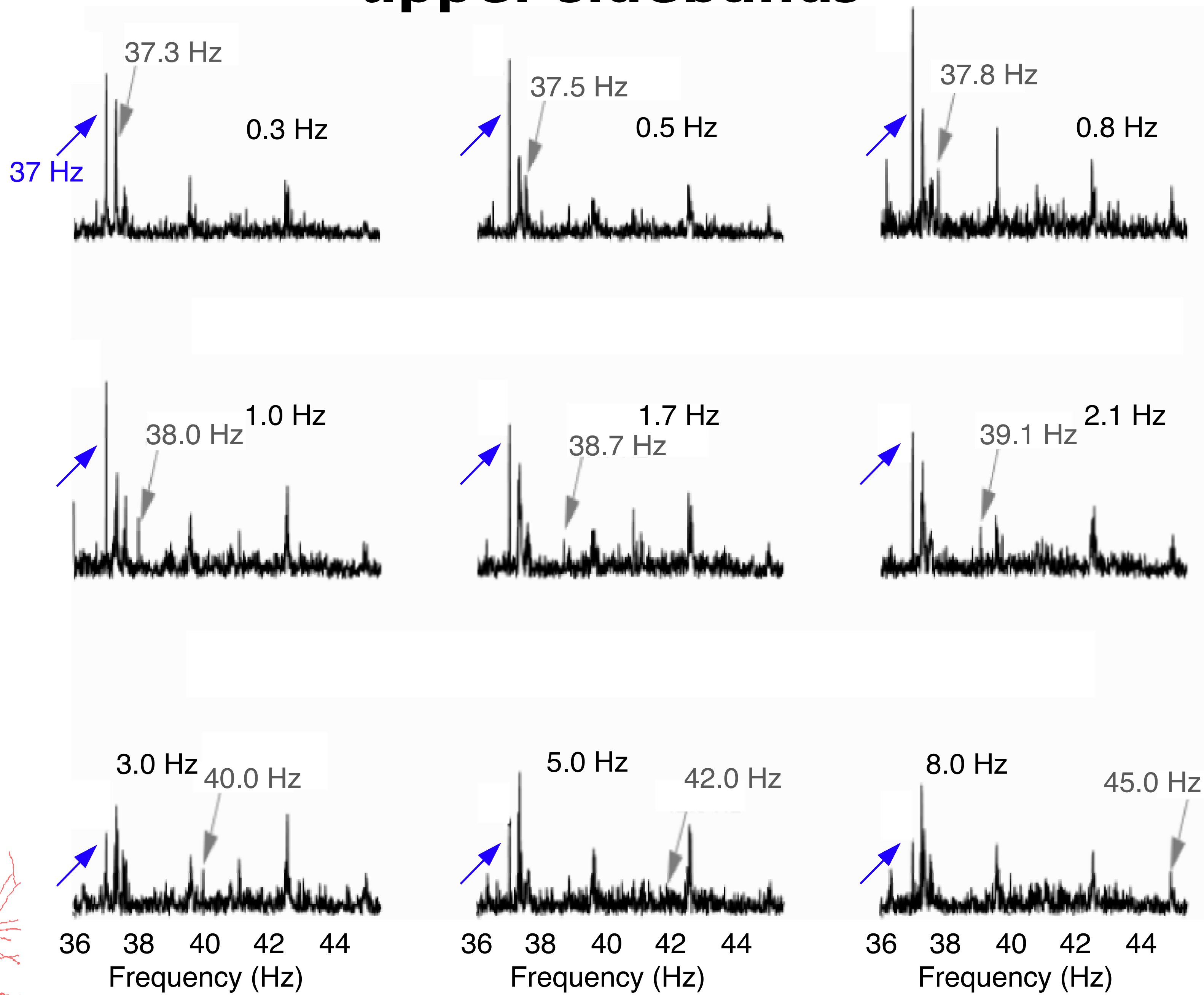
$\alpha_{AM} = 0 \text{ or } 2\pi$

Neural Response Phase Encoding Parameter

$\alpha_{PM} = \pi$

Spectral Sideband Responses

upper sidebands

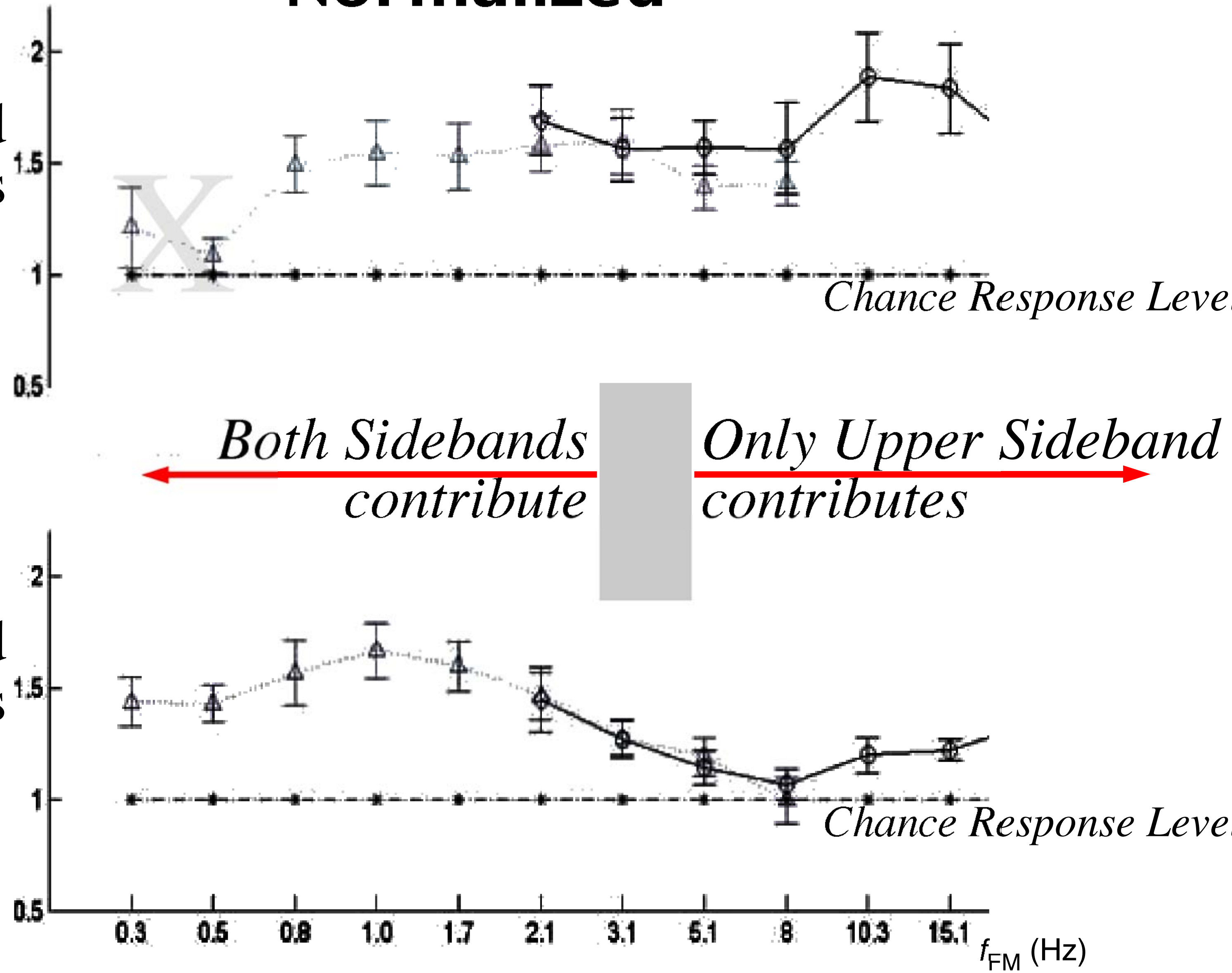


Sideband Responses

Normalized

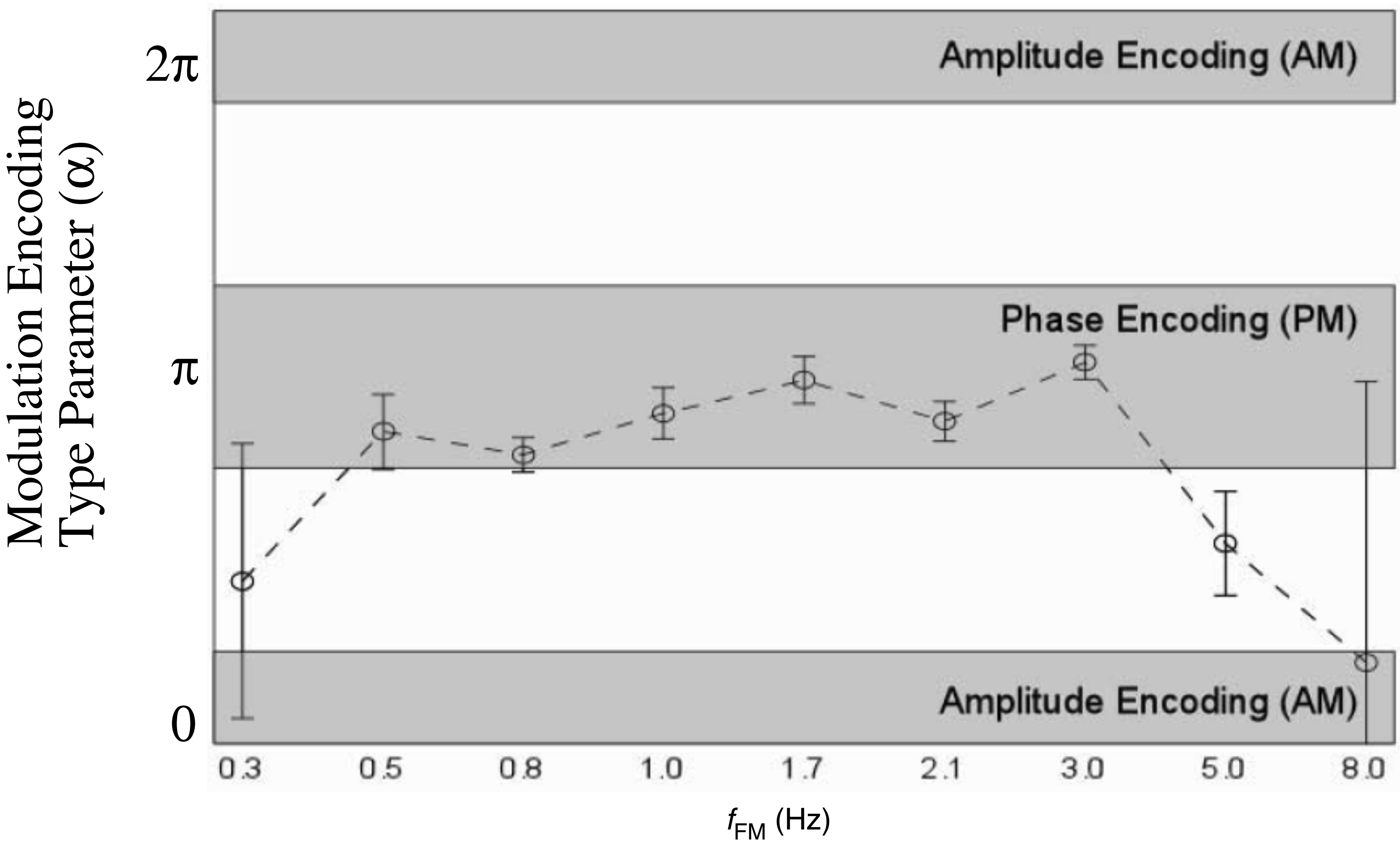
Upper Sideband Responses

Lower Sideband Responses

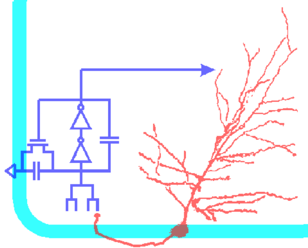


Modulation Encoding, with coding transition at f_{FM} ~ 5 Hz

Modulation Encoding Type



Phase Modulation Encoding below $f_{FM} \sim 5$ Hz



Conclusions

- MEG can address questions of Neural Coding
    - Coarseness of Localization not Intrinsic Obstacle
    - Modulation encoding gives family of response types
- Combined AM/FM modulations are encoded in Auditory Cortex
    - Phase Modulation seen at lowest FM rates
    - Modulation Encoding changes at higher rates
- Single Sideband Modulation unexpected
    - Speculate: Single Modulation Encoding type?
    - Or: Two populations of AM and PM encoding neurons whose phase happens to cancel in lower sideband?