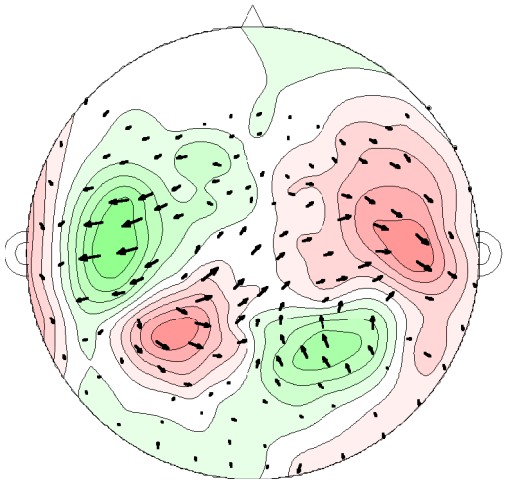
Magnetoencephalography and Auditory Neural Representations



Jonathan Z. Simon
Nai Ding
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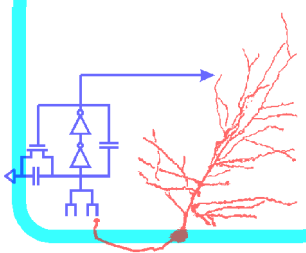
SBEC 2010



Magnetoencephalography (MEG)

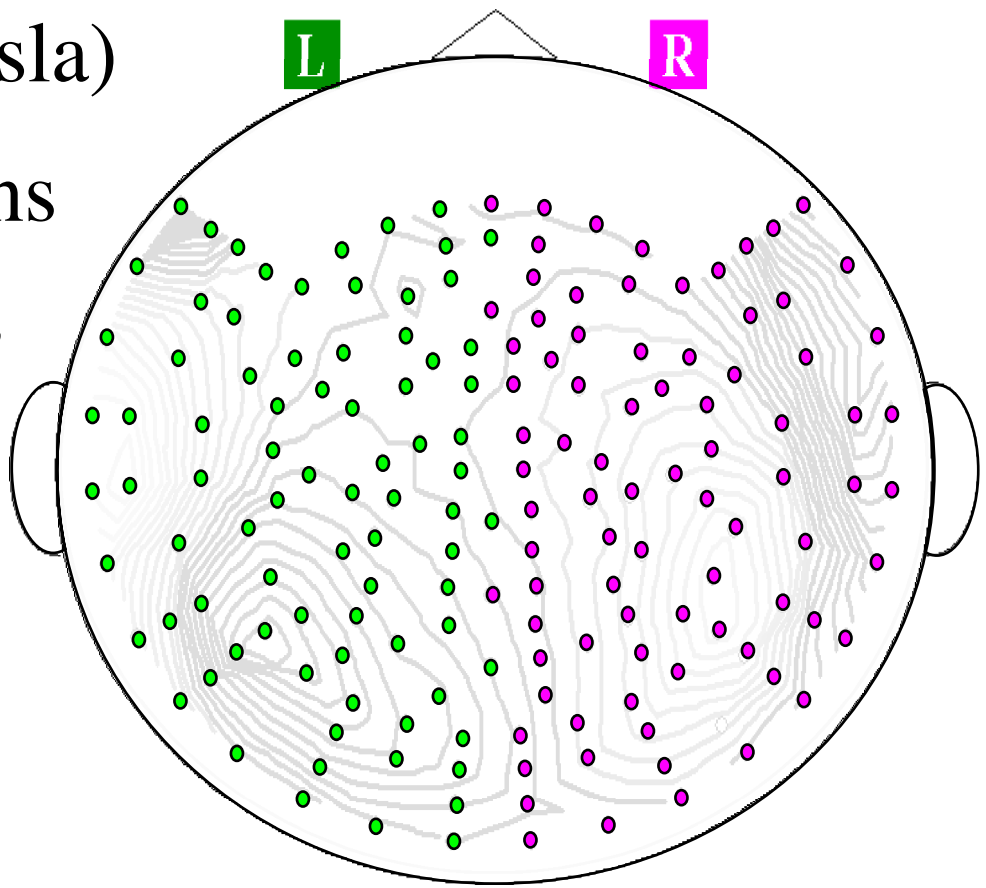
- Non-invasive, Passive, Silent Neural Recordings
- Simultaneous Whole-Head Recording (~200 sensors)
- Sensitivity

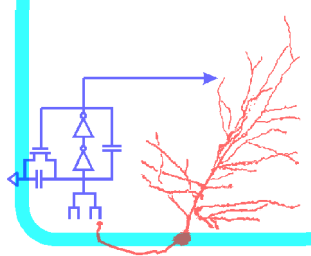
  high: ~100 fT (10^{-13} Tesla)

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

  coarse: ~1 cm

  ambiguous



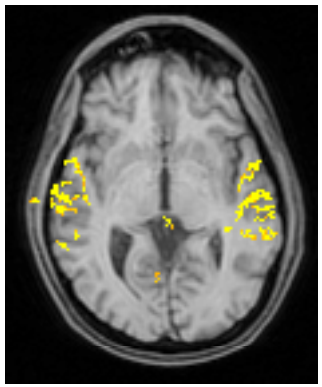


Functional Imaging

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

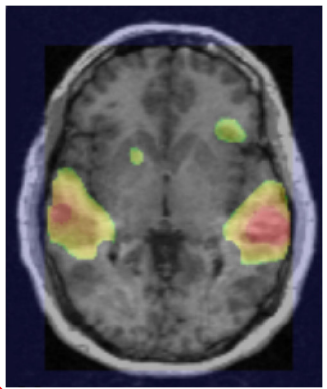
Hemodynamic techniques

Functional magnetic resonance imaging
fMRI



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

Positron emission tomography
PET

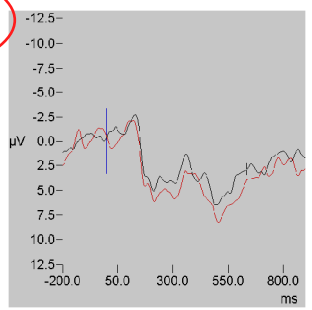


PET, EEG require across-subject averaging

fMRI and MEG can capture effects in single subjects

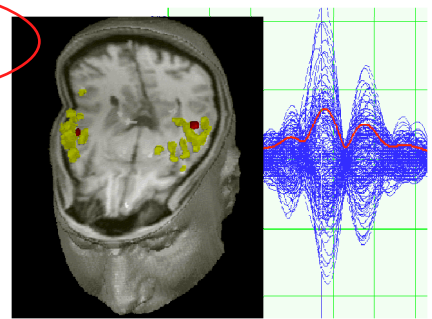
Electromagnetic techniques

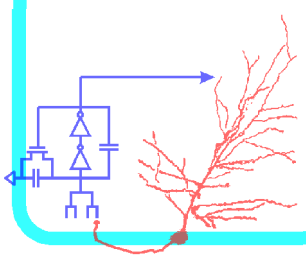
Electroencephalography
EEG



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

Magnetoencephalography
MEG





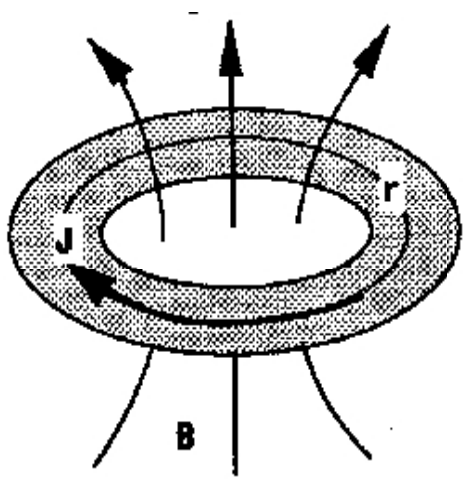
Magnetic Flux Detectors

Superconductivity →

Magnetic flux quantization →

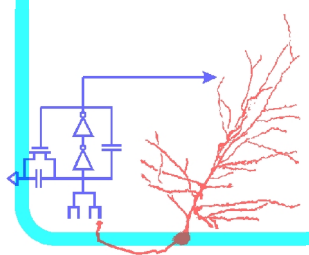
Josephson Effect →

SQUID = Superconducting Quantum Interference Device

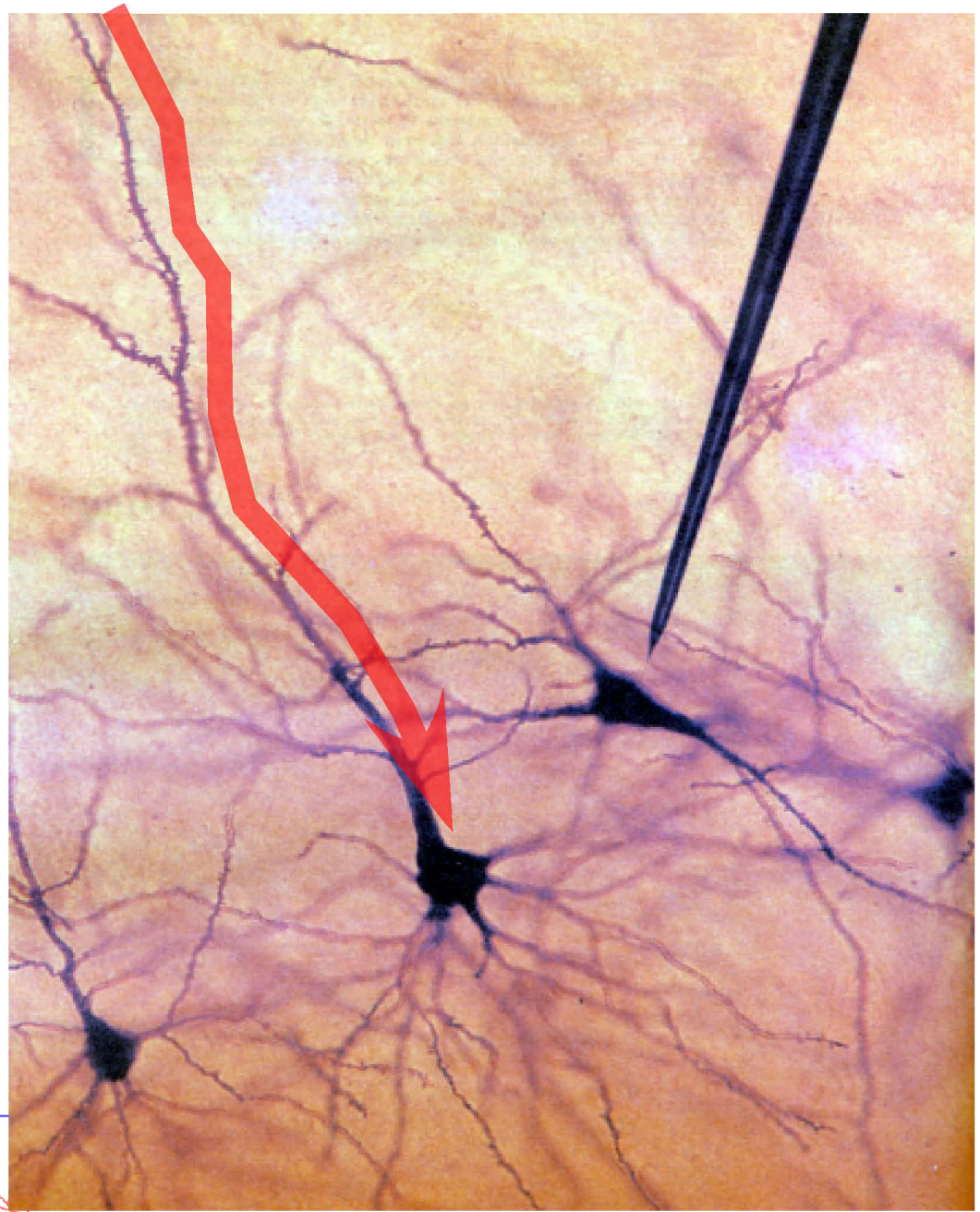


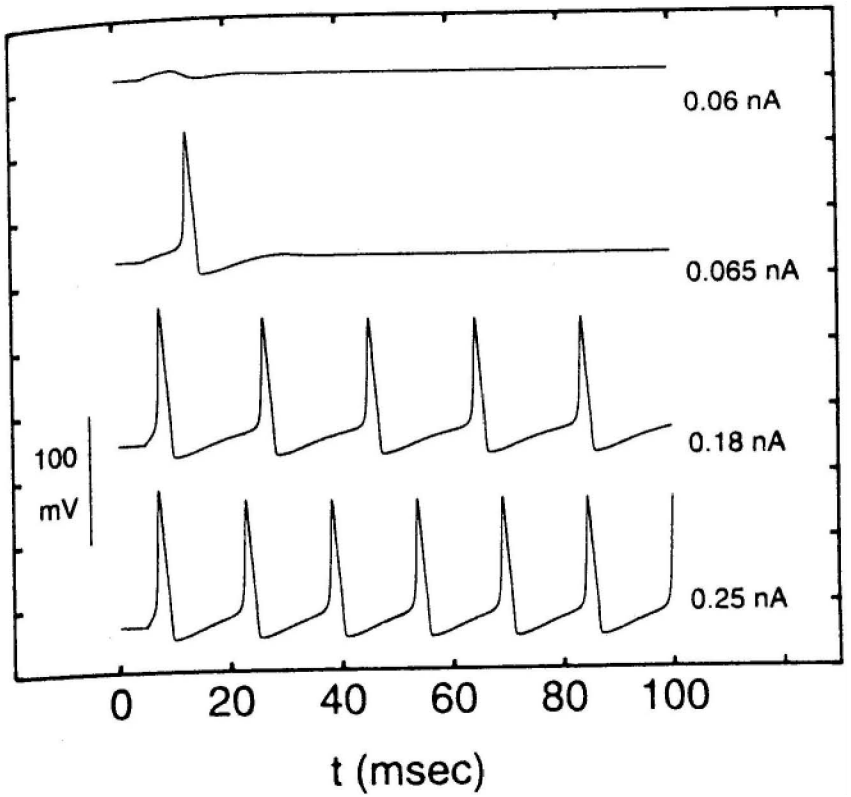
$$\Phi = n \frac{h}{2e} = n \Phi_0$$

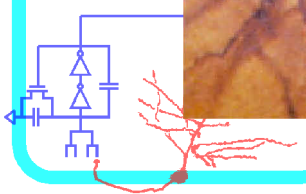
$$\Phi_0 = \frac{h}{2e} = 2.07 \quad 10^{-15} \text{ Wb}$$



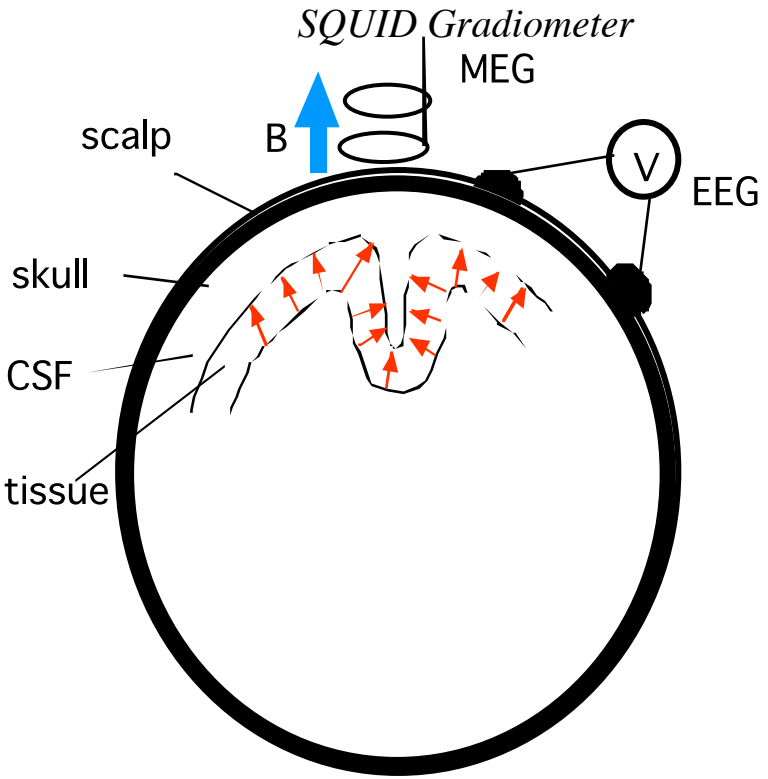
Neural Activity = Neural Current



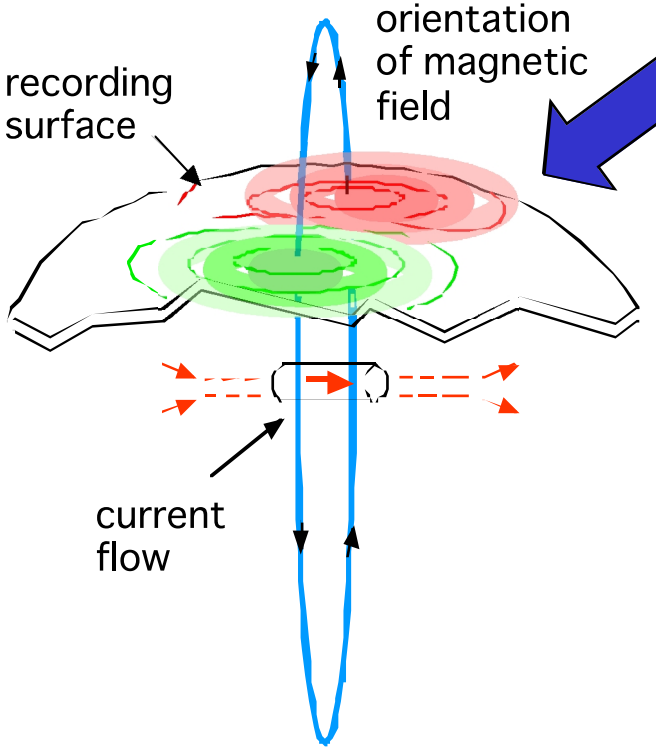




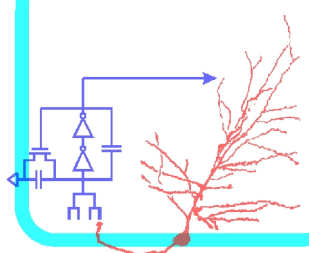
MEG Magnetic Signal



Magnetic Dipolar Field (Projection)

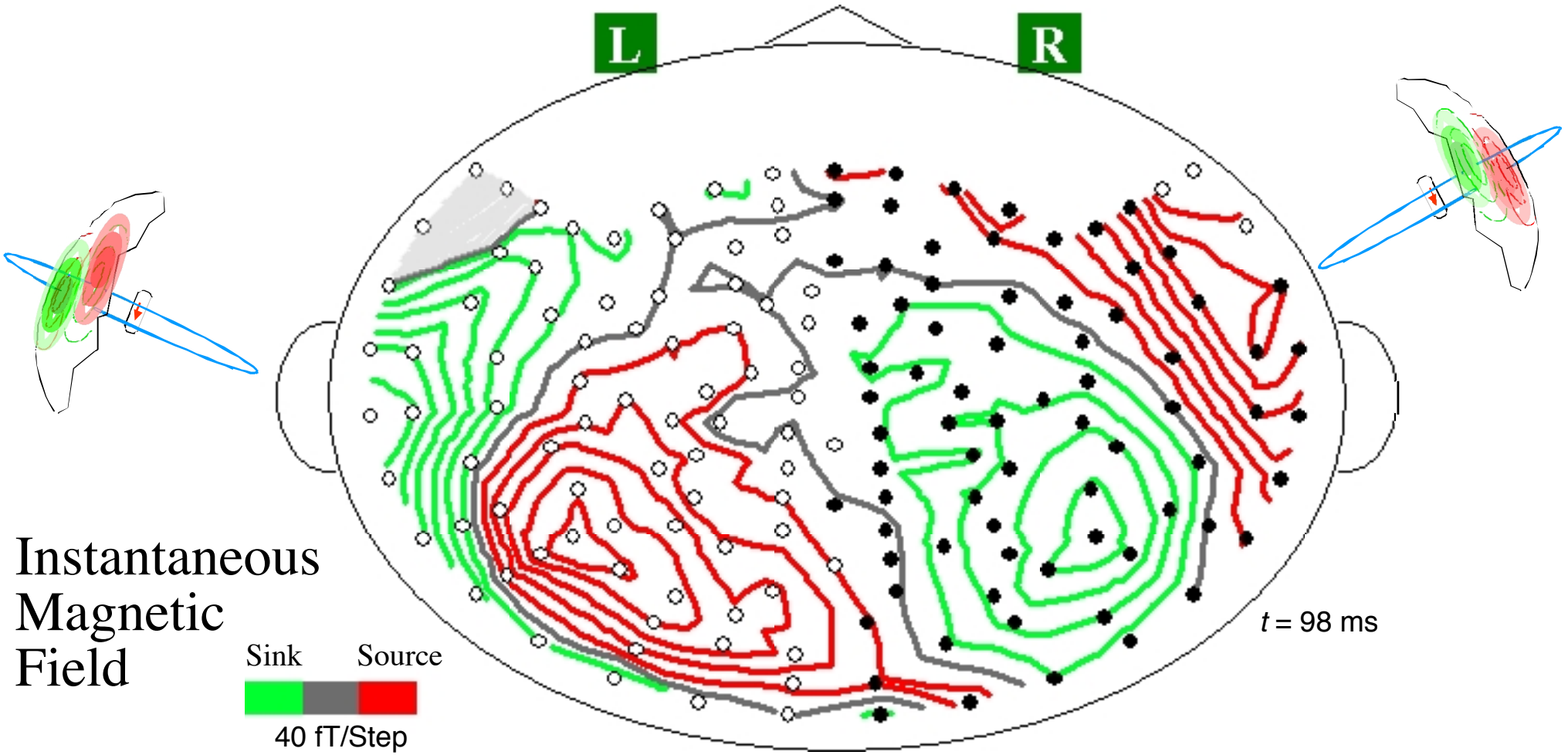


- Direct electrophysiological measurement
  - not hemodynamic
  - real-time
- No unique solution for distributed source



MEG Response

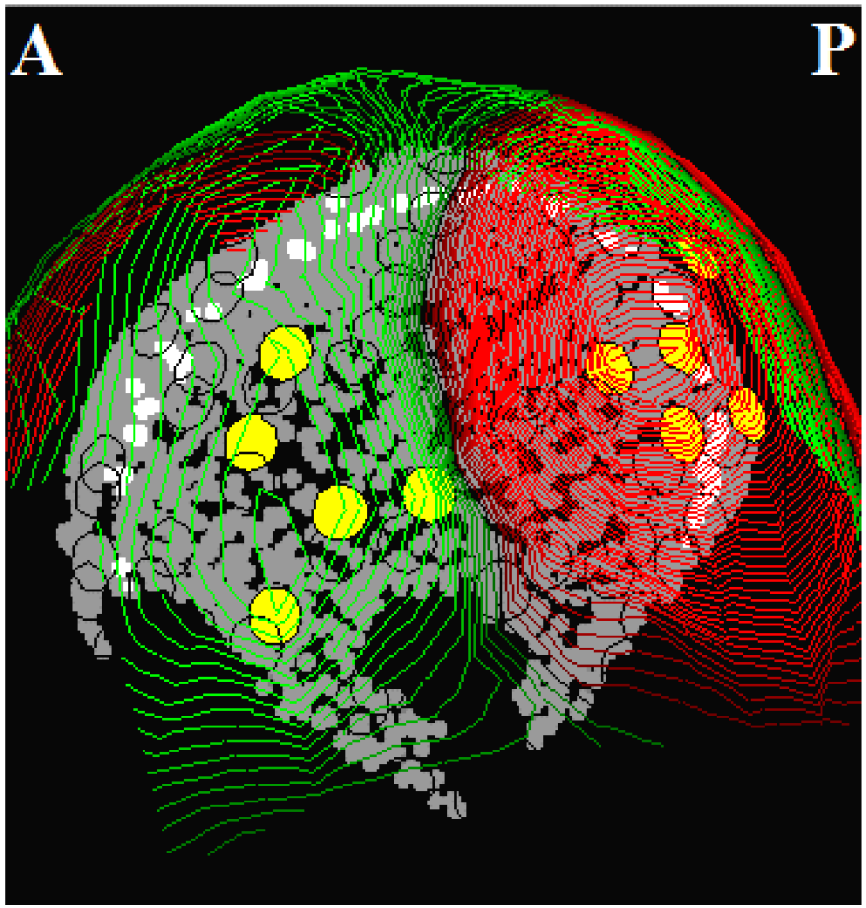
Flattened Isofield Contour Map



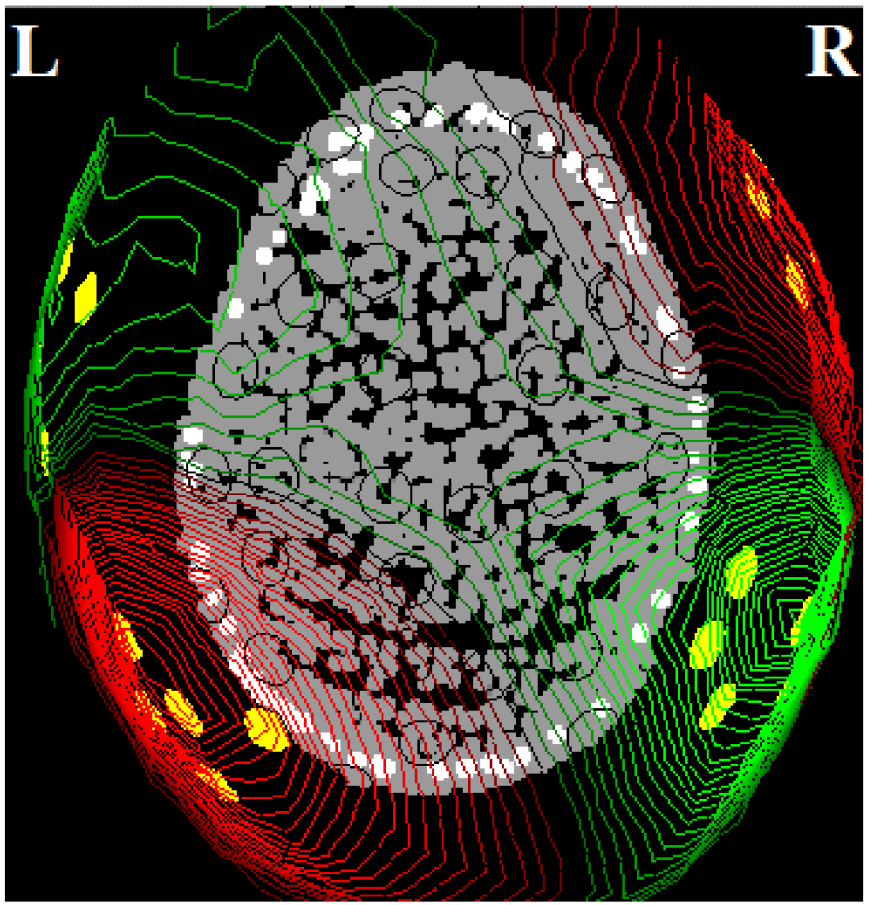
MEG Response

3-D Isofield Contour Map

Sagittal View



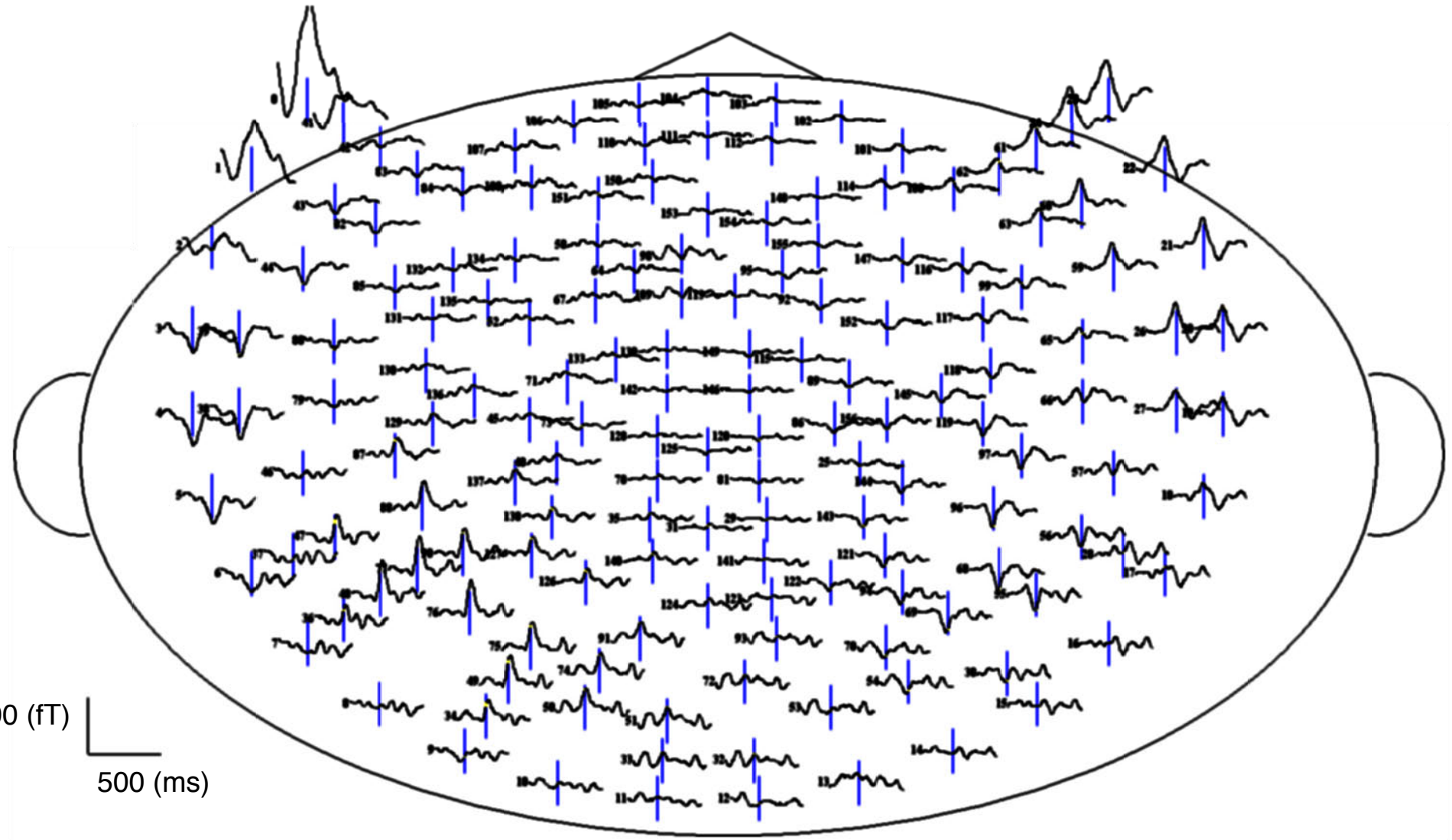
Axial View

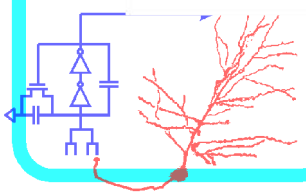


Chait, Poeppel and Simon,
Cerebral Cortex 2006

MEG Response

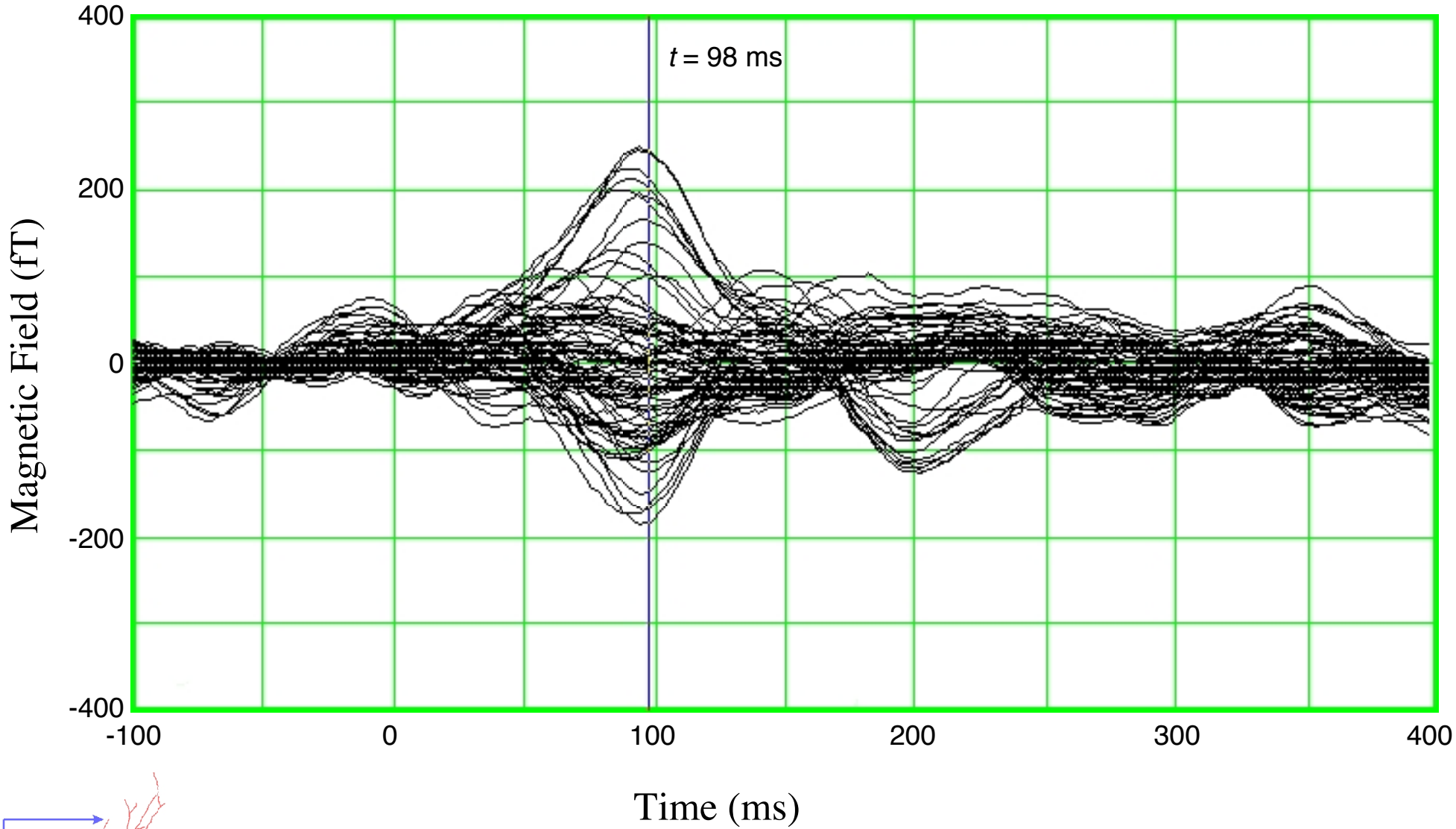
Spatial Map of Time Series

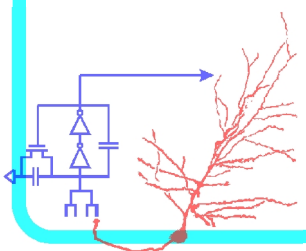




MEG Response

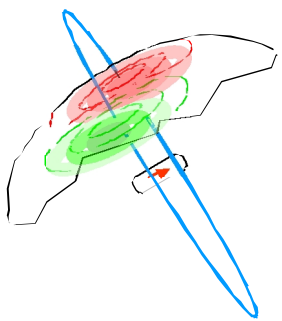
Butterfly Plot



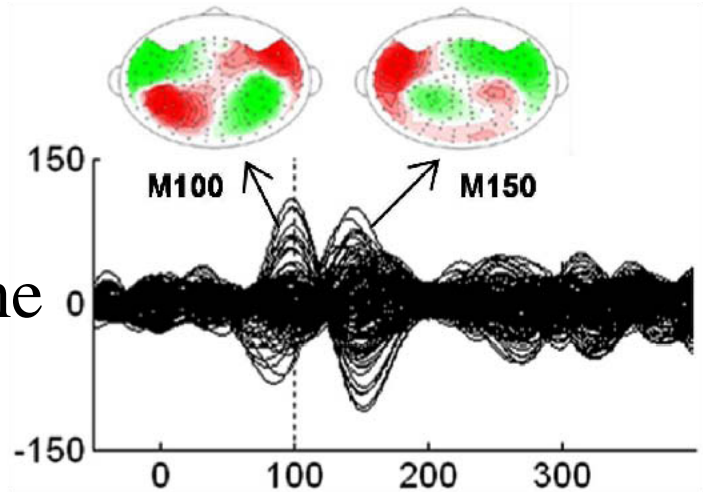


Time Course of MEG Responses

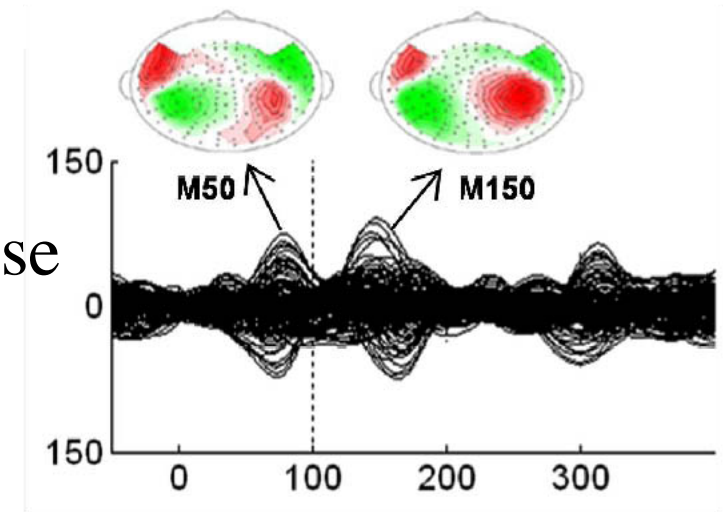
Evoked Responses
MEG Events Time-Locked
to Stimulus Event

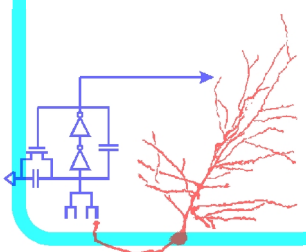


Pure Tone



Broadband Noise



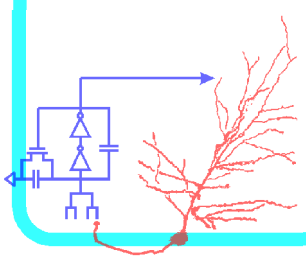


An Alternative to Time: Frequency

- Use Stimuli localized in Frequency rather than time
- Examine Response at Same Frequency
- Stimulus Modulated at Single Frequency

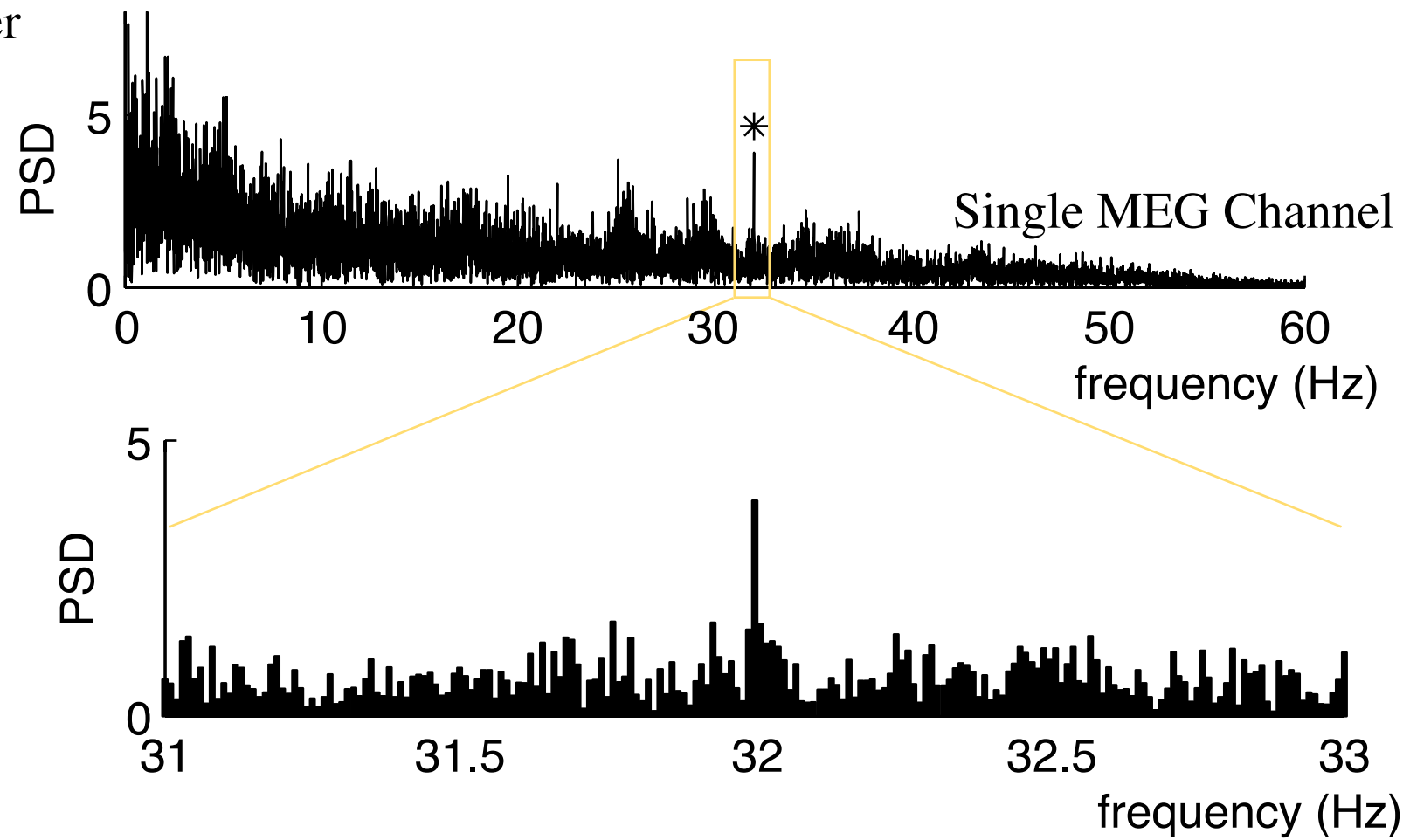
  → ***Steady State Response*** (SSR)

- Measure ***Frequency Response/Transfer Function***

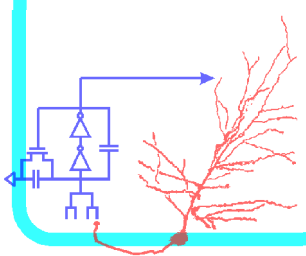


Frequency Response

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

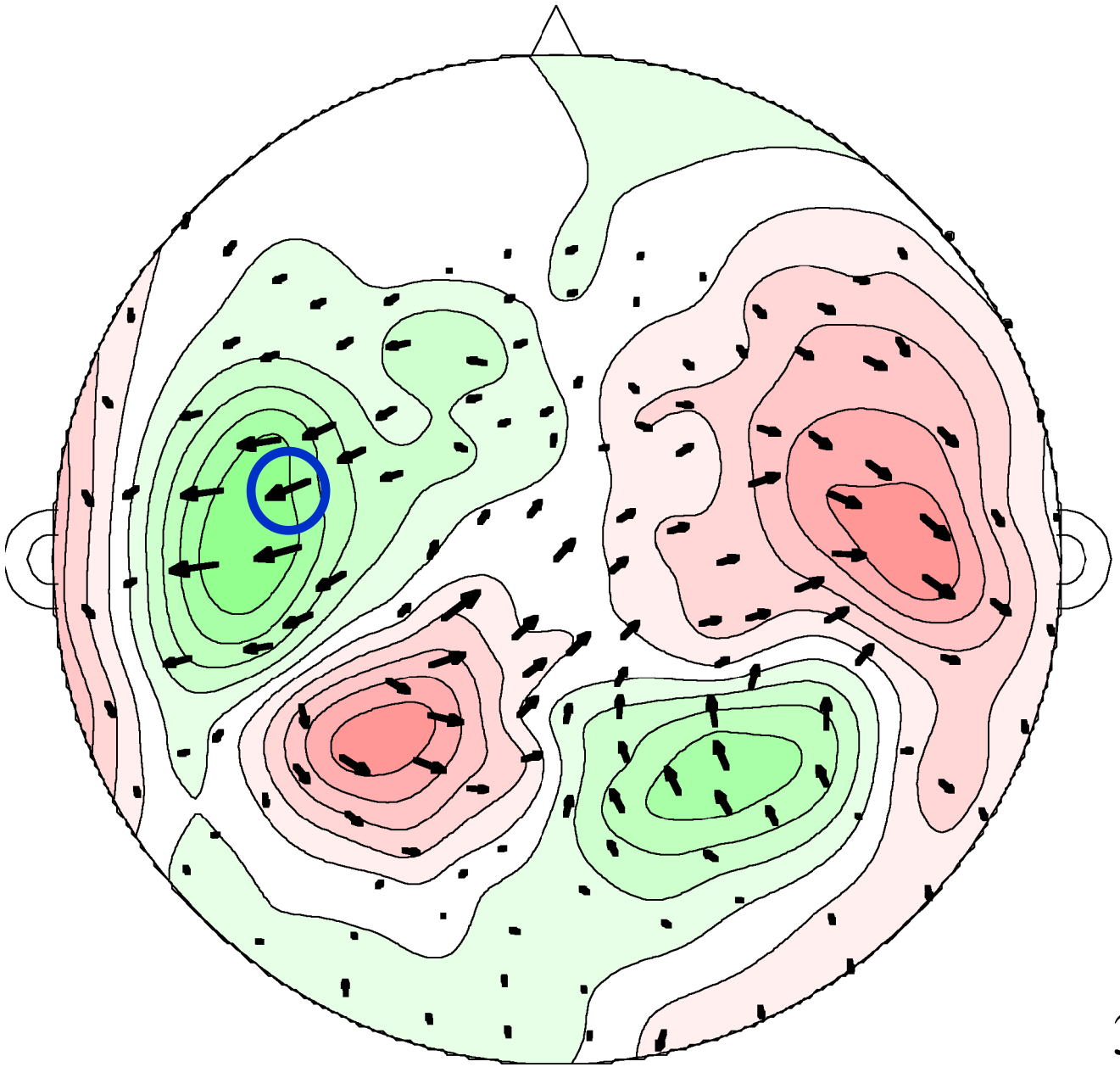


Precise Phase-Locking: 0.01 Hz
Little trial-to-trial jitter

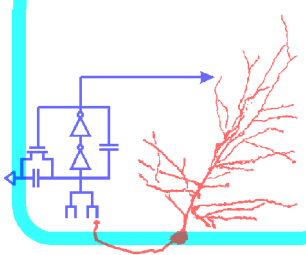


Amplitude + Phase...

Whole Head Steady State Response



32 Hz



What Can We Hear?

- **Spectro-Temporal Features of Any Sound**

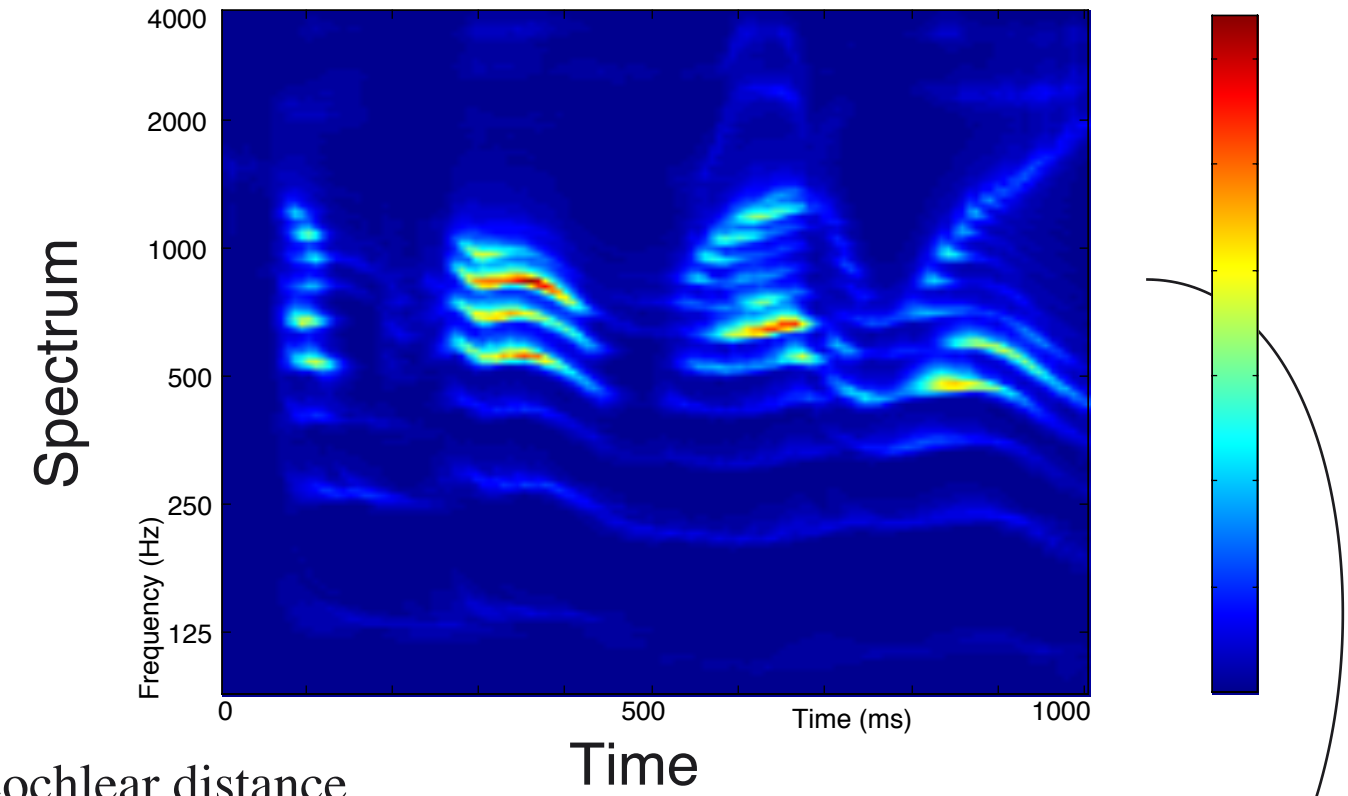
  Spectral content of sound as a function of time.

  Which spectral frequency bands have enhanced power?

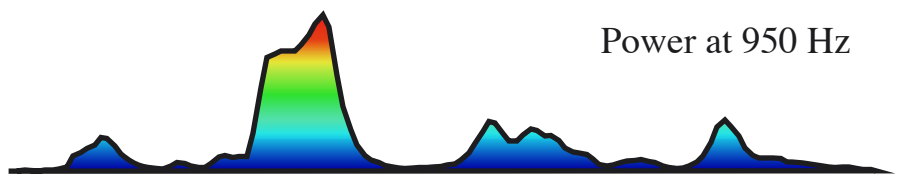
  Which spectral frequency bands have diminished power?

  How do these change as a function of time?

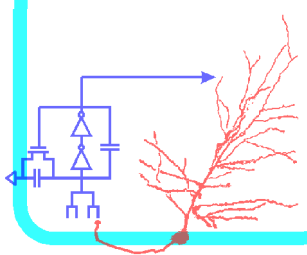
"Come home right away."



log f ~ linear cochlear distance

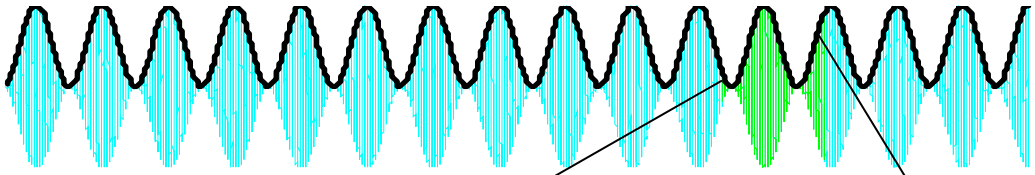


Characterization from frequency cross-section is very limited

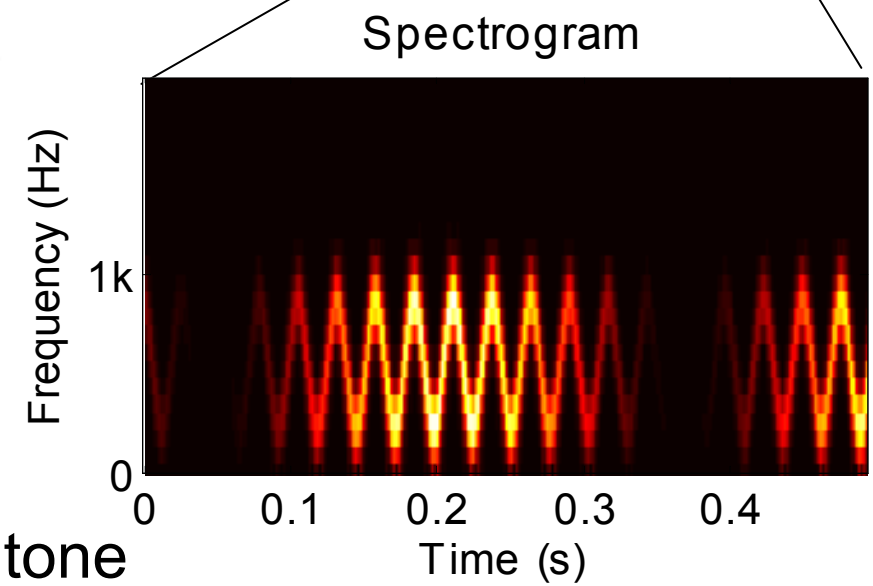


Stimuli

Envelope →



AM rate: 3.1 Hz



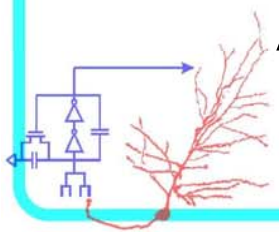
Fine structure →

FM rate: 37.7 Hz

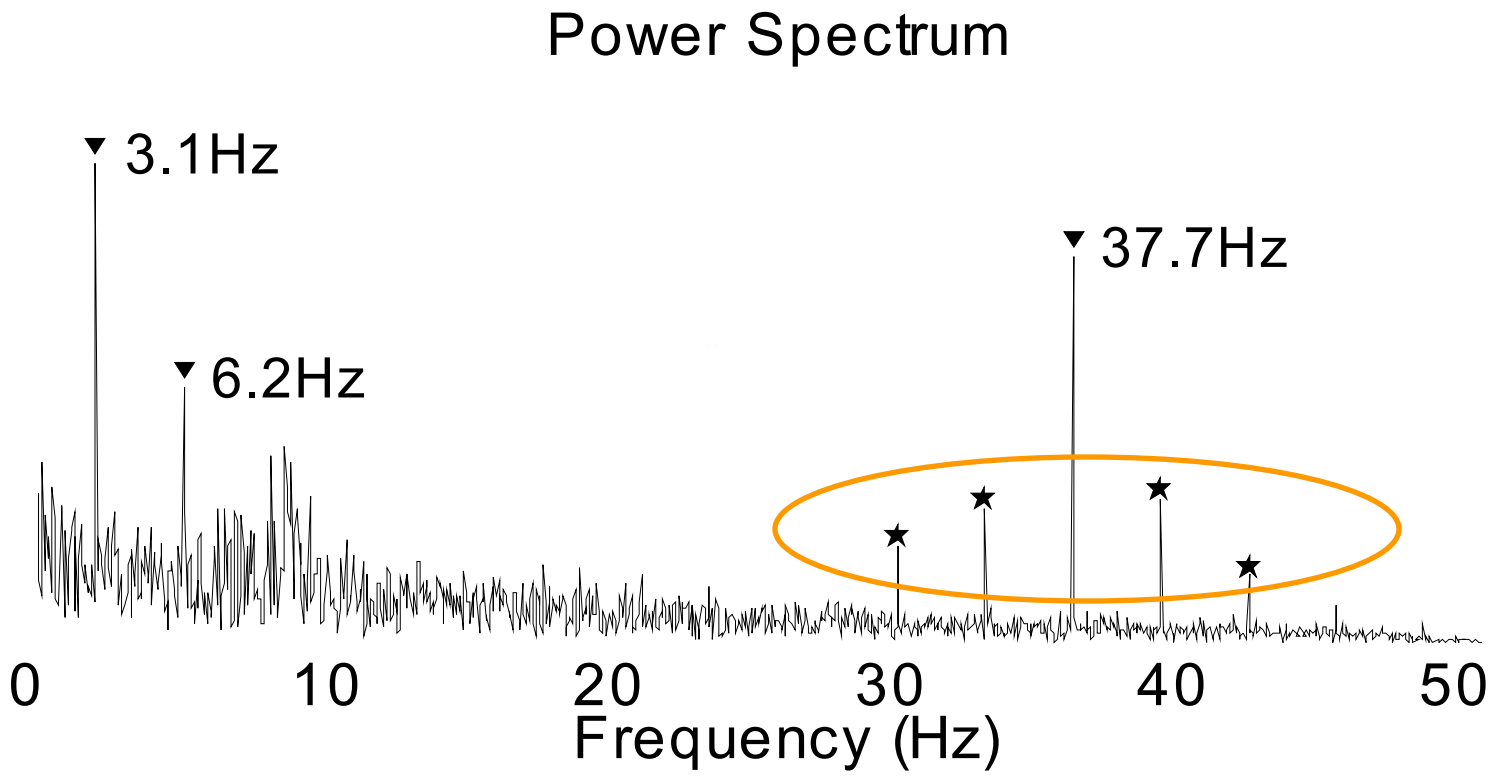
Carrier: 550 Hz pure tone

AM rate: 0.3, 0.7, 1.7, 3.1,4.9, 9.9, 13.8 Hz

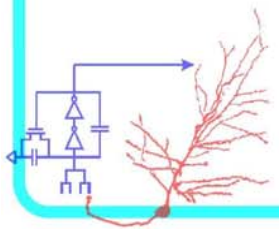
FM rate: 37.7 Hz



Neural Response to Stimuli



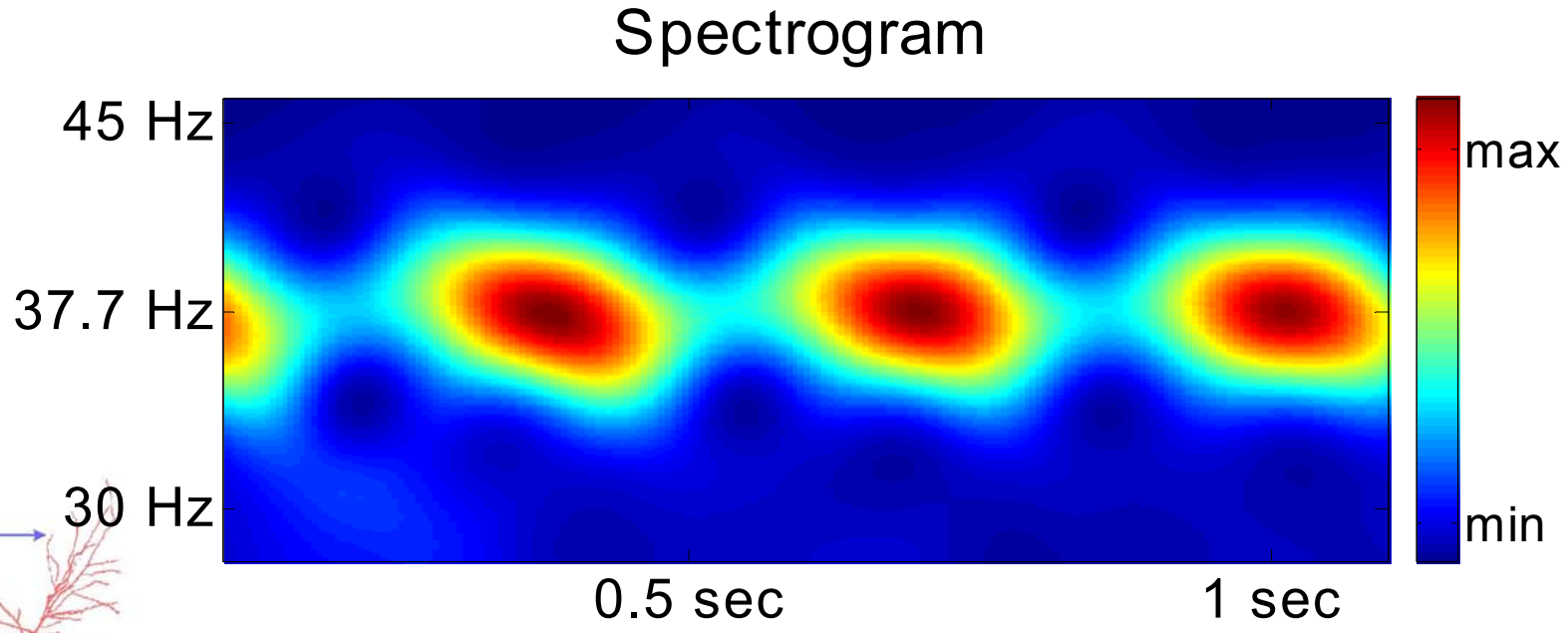
AM rate = 3.1 Hz, FM rate = 37.7 Hz



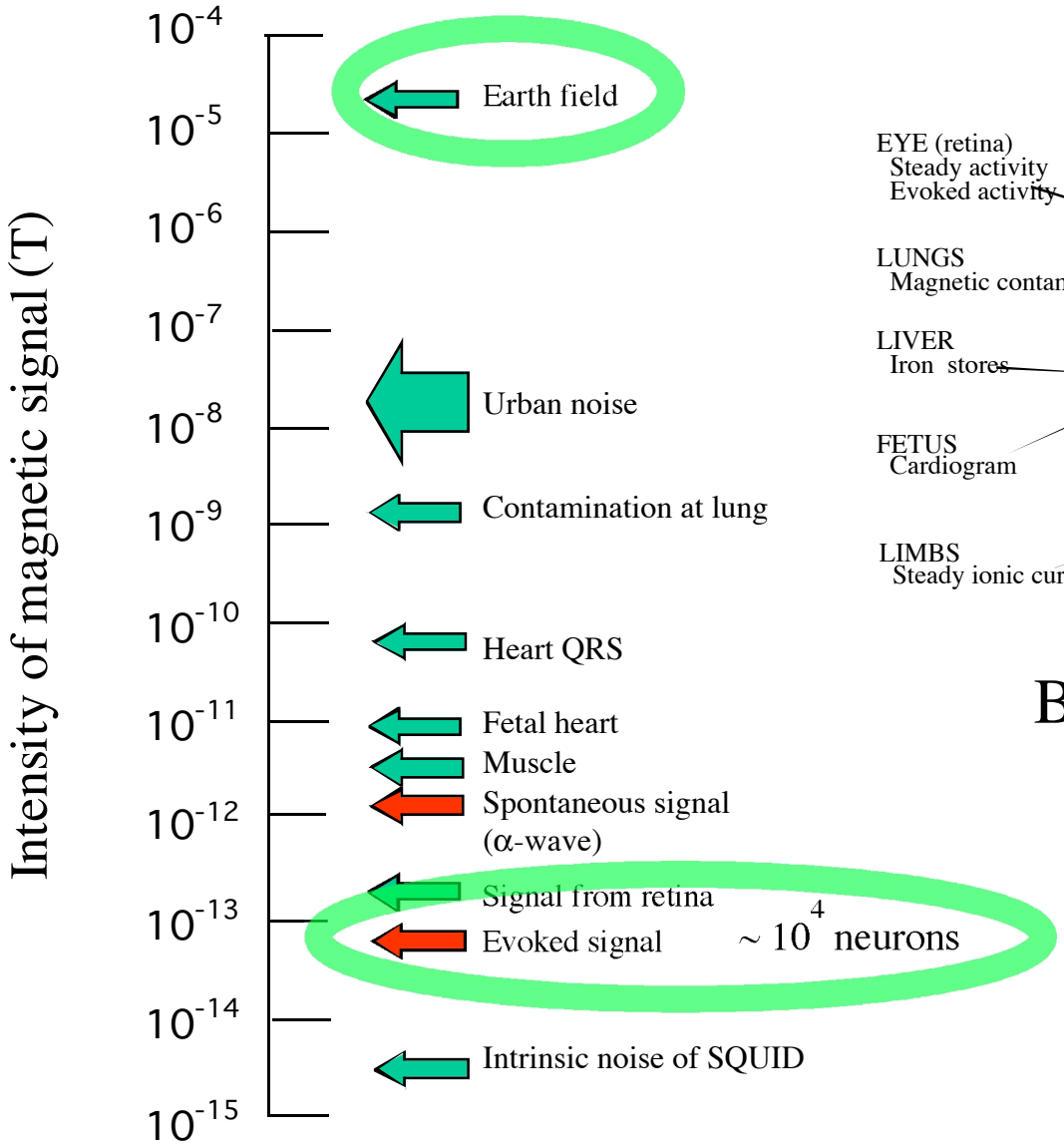
Interactions between Neural Responses

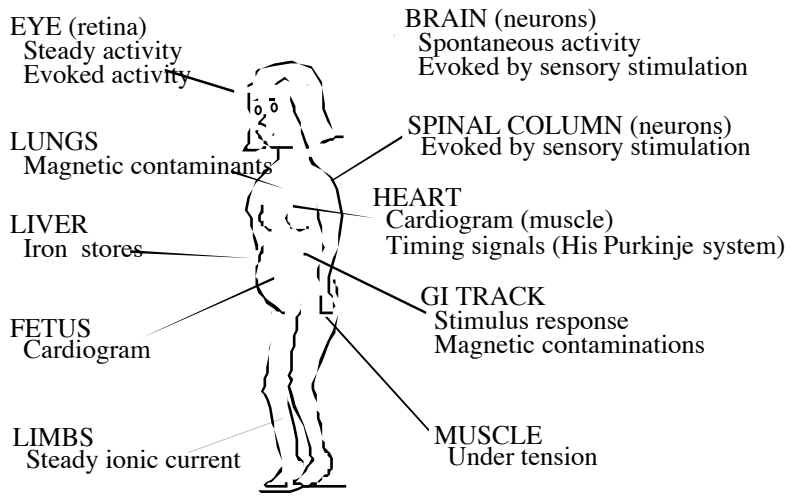
- The power or phase of the neural response at the FM rate is fluctuating with fundamental frequency at the stimulus AM rate.

AM rate = 3.1 Hz, FM rate = 37.7 Hz

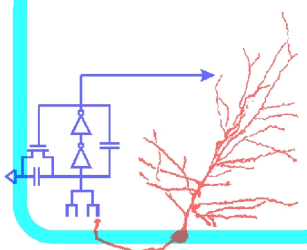


Magnetic Field Strengths





Biomagnetism

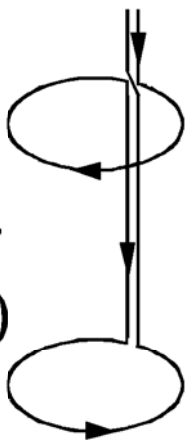


External Noise Reduction Aids

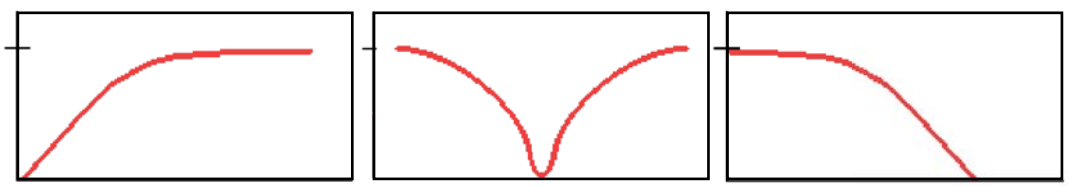
Magnetically shielded room

Magnetic/electromagnetic sheilding

Gradiometers (sensitive to near sources)

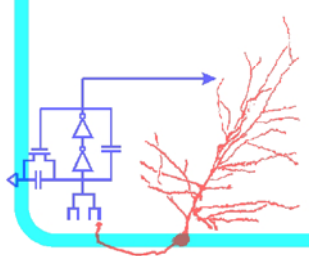


Gradiometer



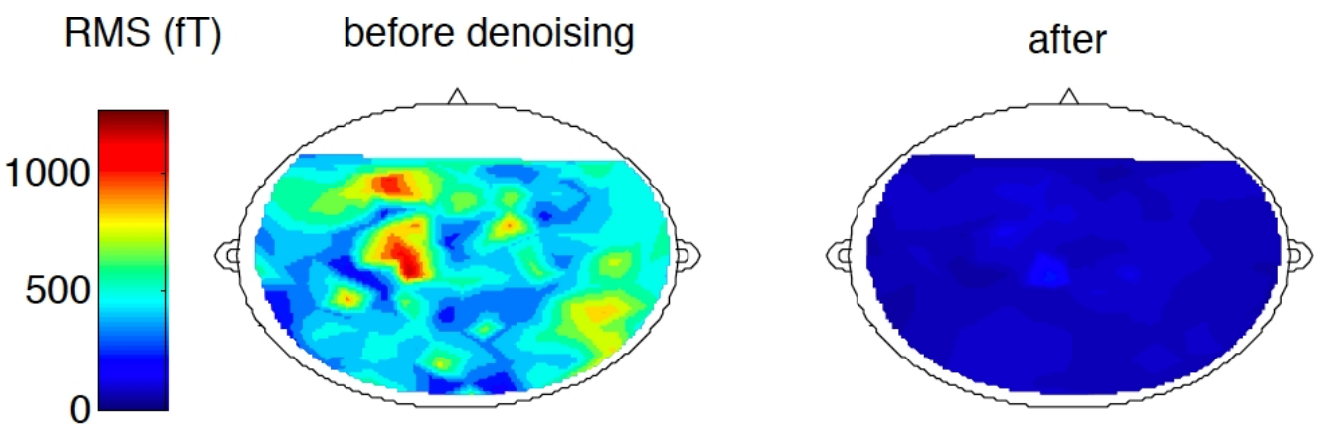
Spectrally Selective Filters

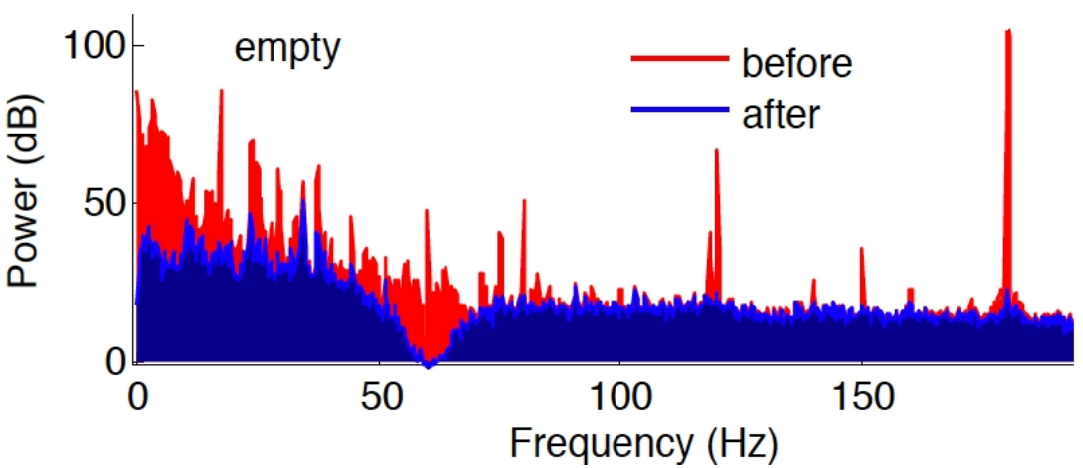
Spectral filtering (high-pass, notch, low-pass)



TSPCA Example

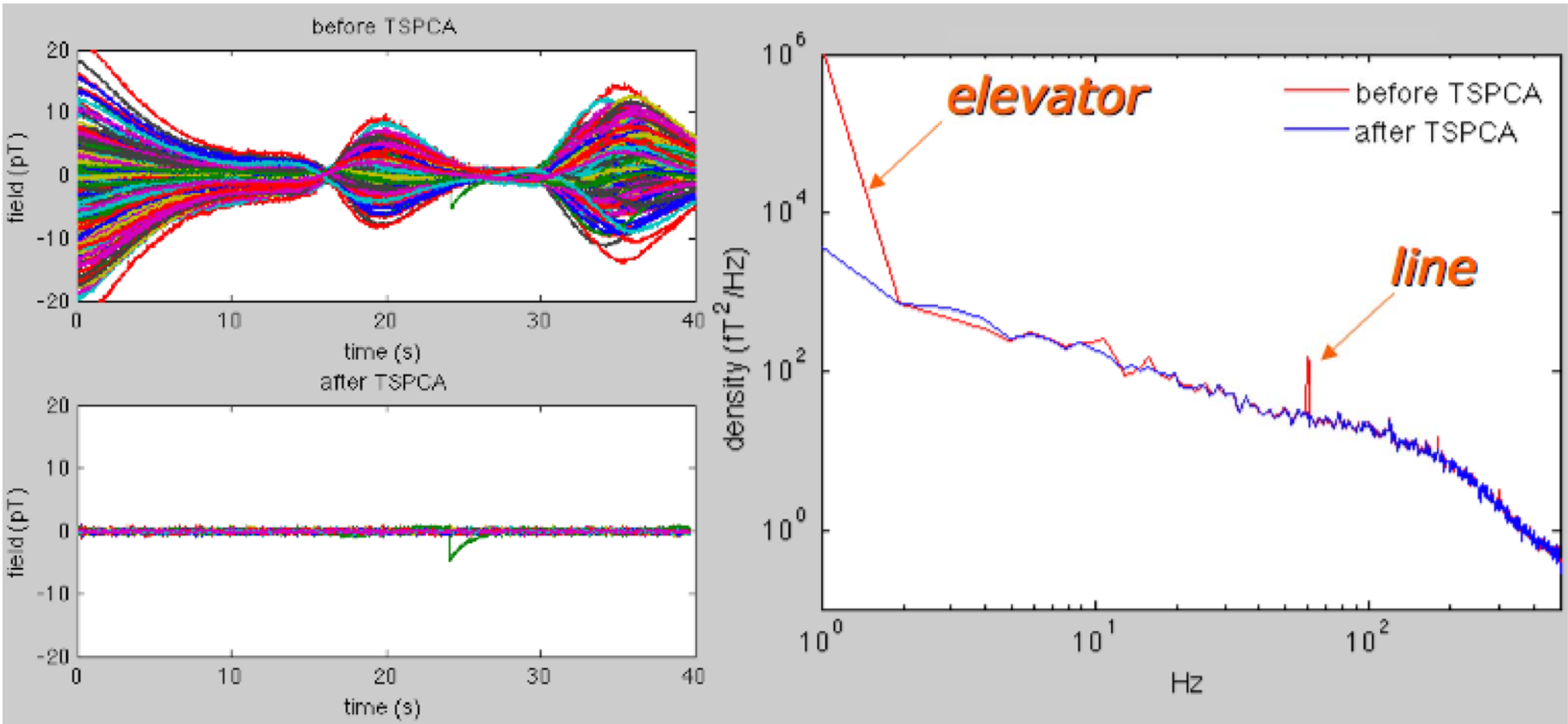
Empty Chamber

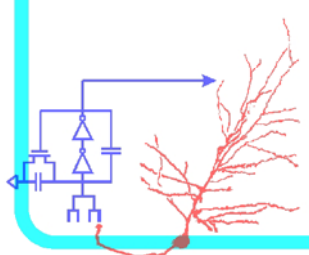




U. Maryland/KIT

TSPCA Example

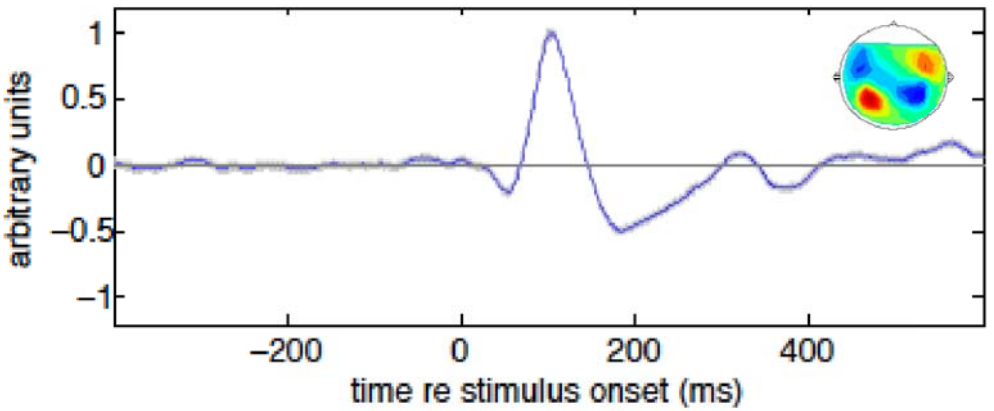




ATR MEG
(Advanced Telecommunications Research, Kyoto)
Computational Sensorimotor Systems Laboratory

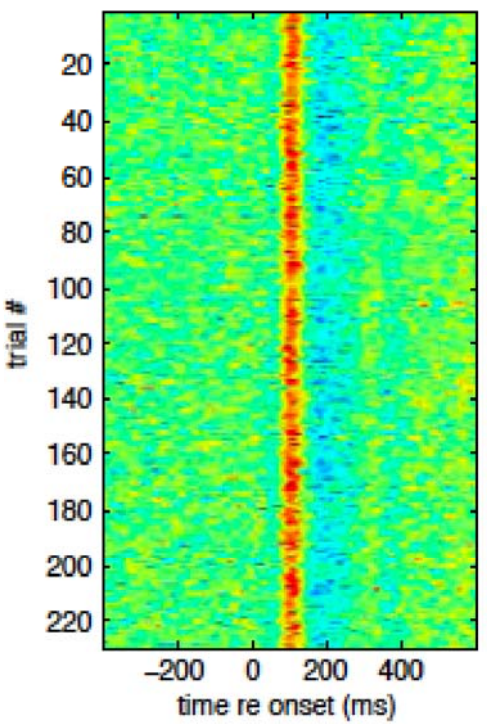
DSS Example

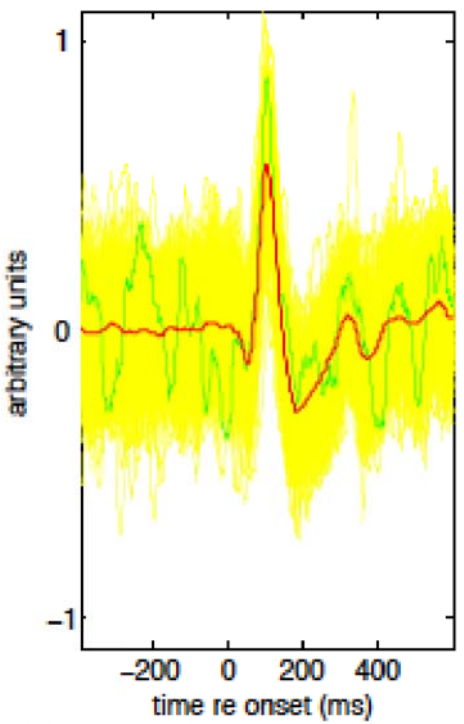
Best Component:



= output of Spatial Filter with the most reproducible linear combination of sensors

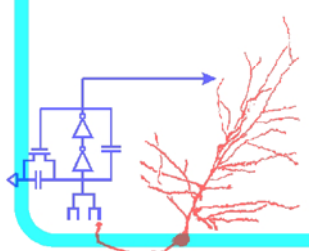
Single trials passed through spatial filter of best component





red: average

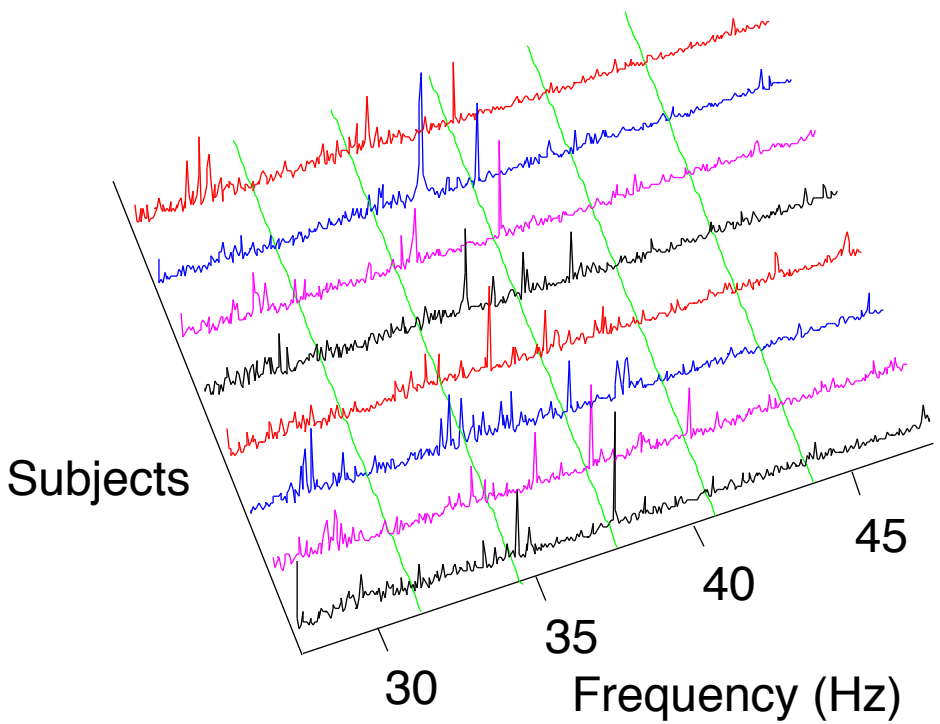
yellow & green: individual trials



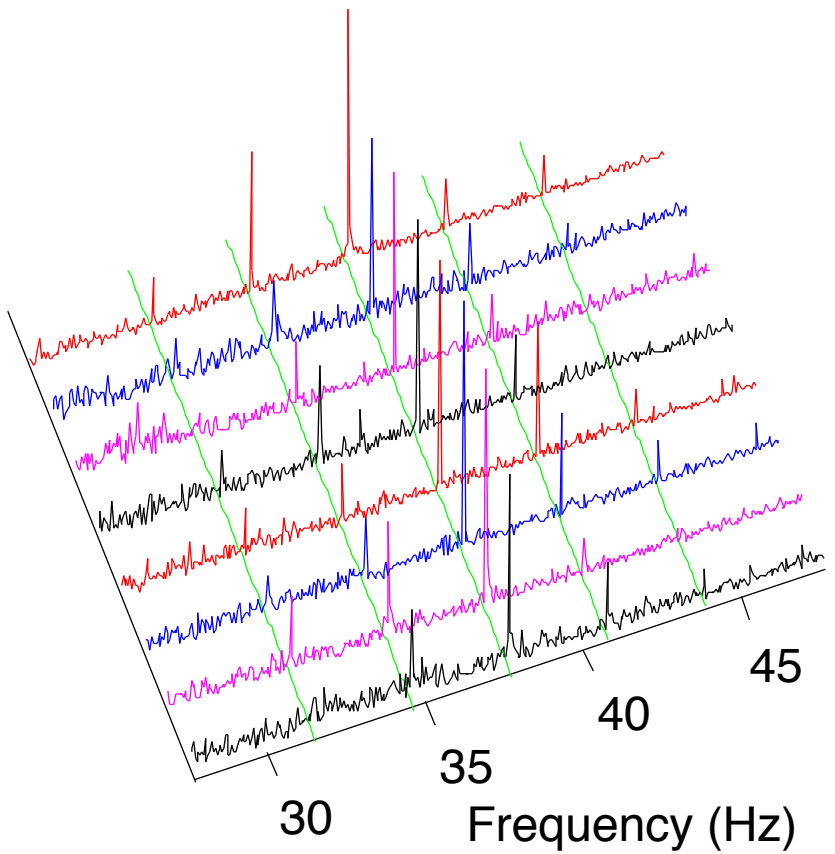
DSS Example

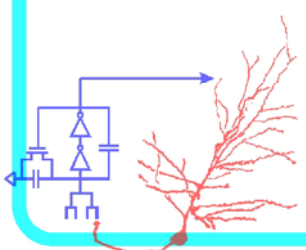
Spectra of MEG Steady State Response (to dual modulation)

Before DSS (20 Best Channels)



First DSS component

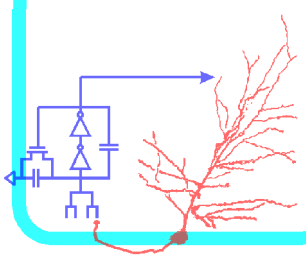




U. Maryland/KIT, courtesy of Nai Ding

Summary

- Magnetoencephalography (MEG)
  - Directly generated by neural currents
  - Excellent time/frequency resolution
  - Spatial Localizability an open question
- In the presence of a fast FM, a slower AM is encoded twice: directly and as a second order modulation
  - Phase Modulation seen at lowest FM rates
  - Modulation Encoding changes at higher rates
- Noise is a problem
  - But a problem with solutions



Thank You

Thanks also to NIH:
R01 AG 027573
R01 DC 007657
R01 DC 008342
R01 DC 005660