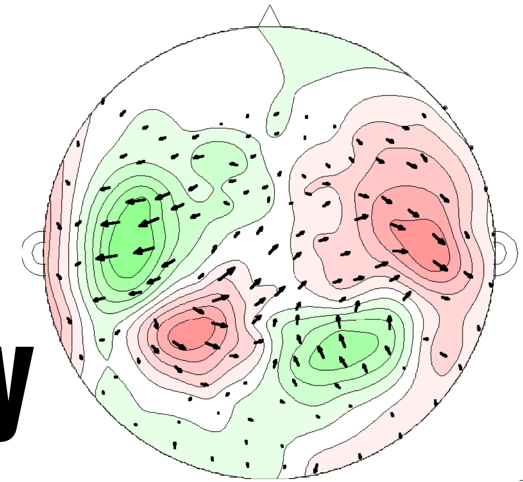
Fully Complex Magnetoencephalography



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MEG — Magnetoencephalography

- Non-invasive, Passive, Silent
- Simultaneous Whole Head recordings

  160 magnetic sensors (3 reference)

- Exquisitely Sensitive

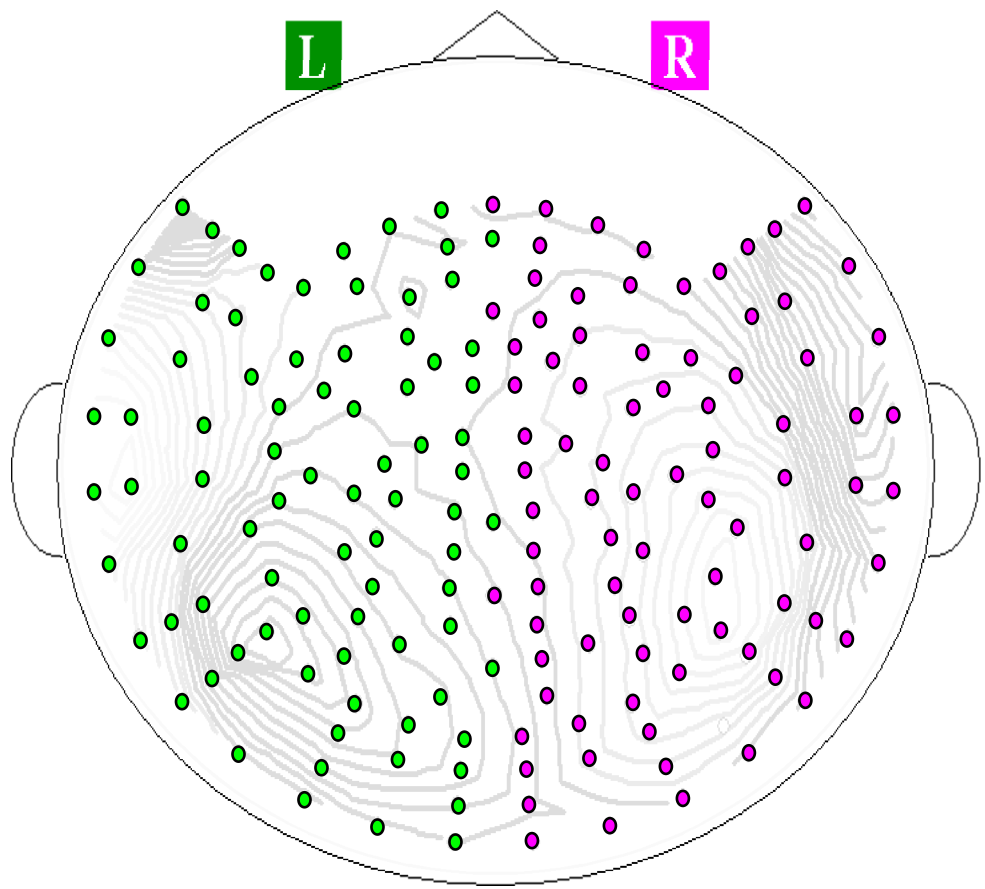
  ~ 100 fT (10^{-13} Tesla)

  ~ 10^4 neurons

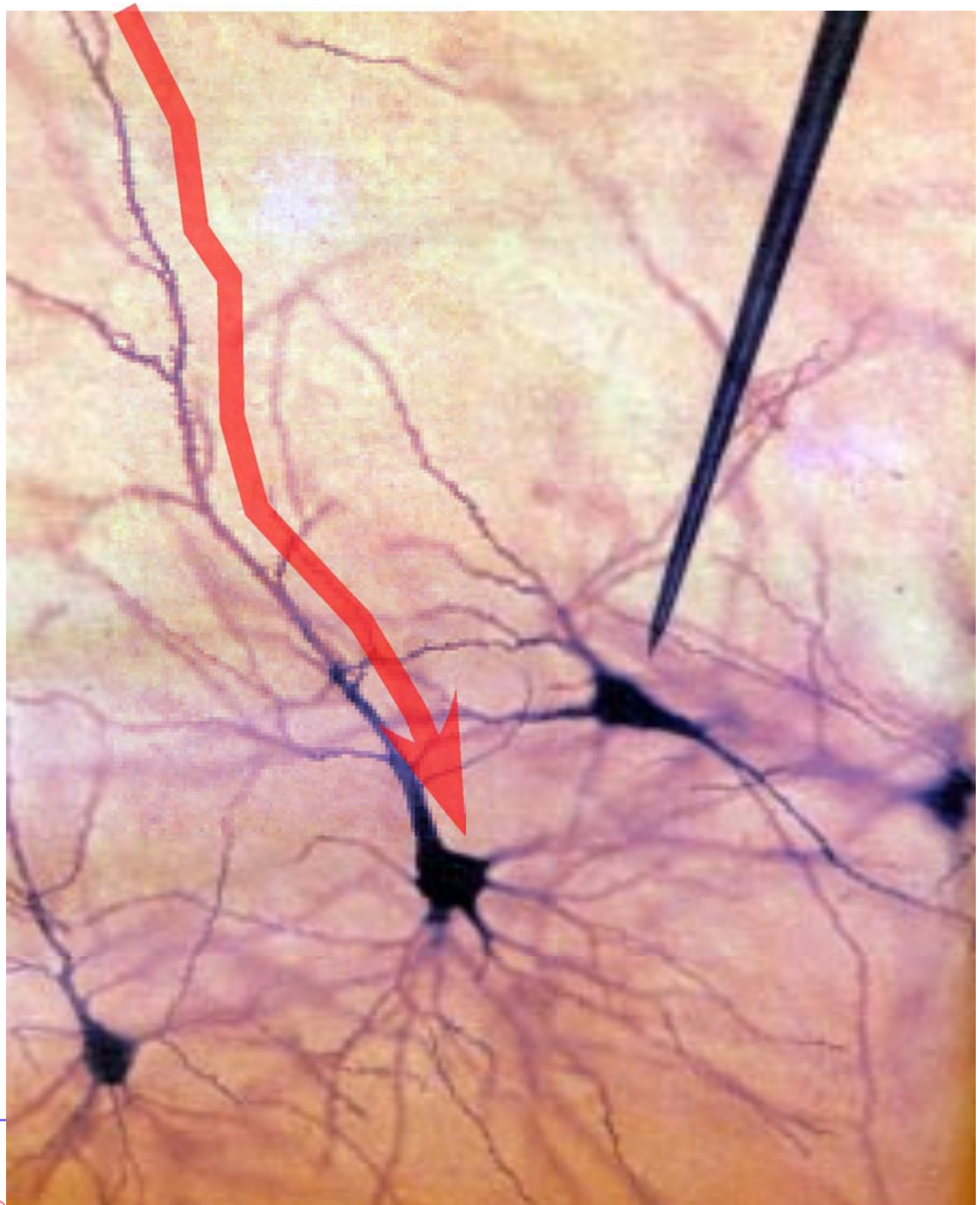
- Temporal Resolution

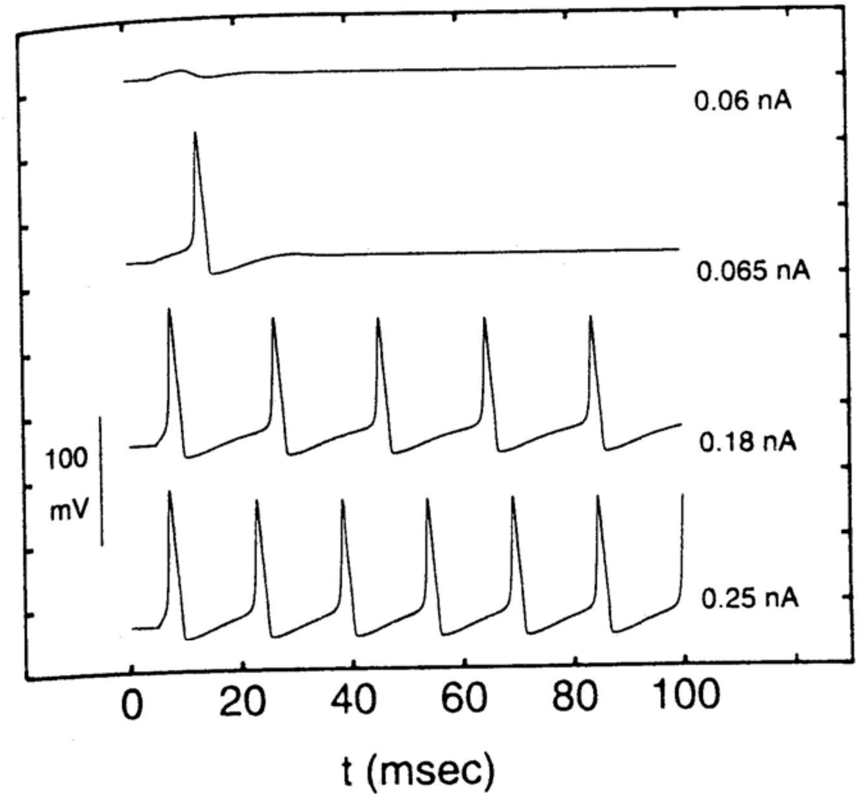
  ~ 1 ms

  (c.f. fMRI: ~1 s)

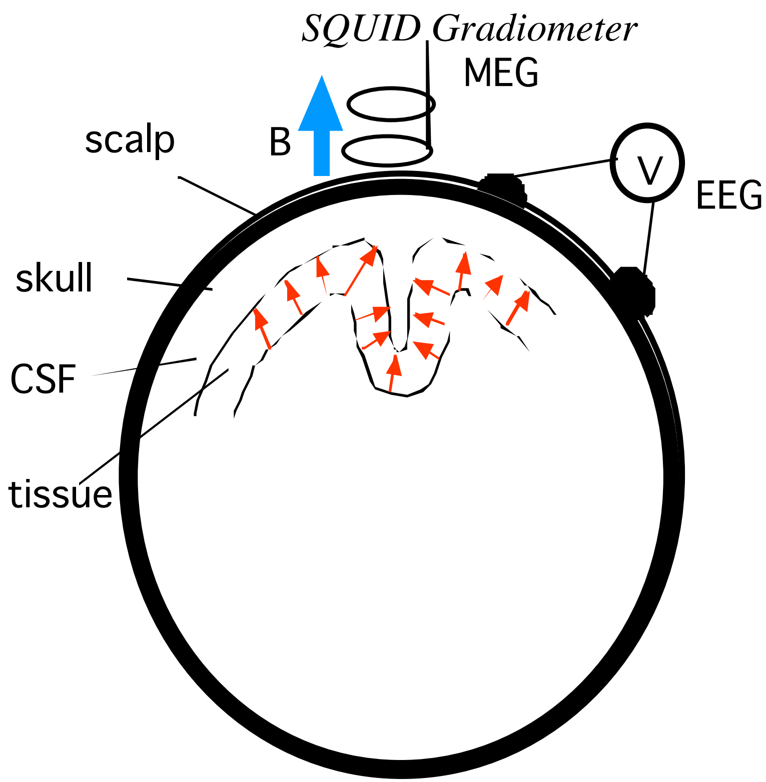


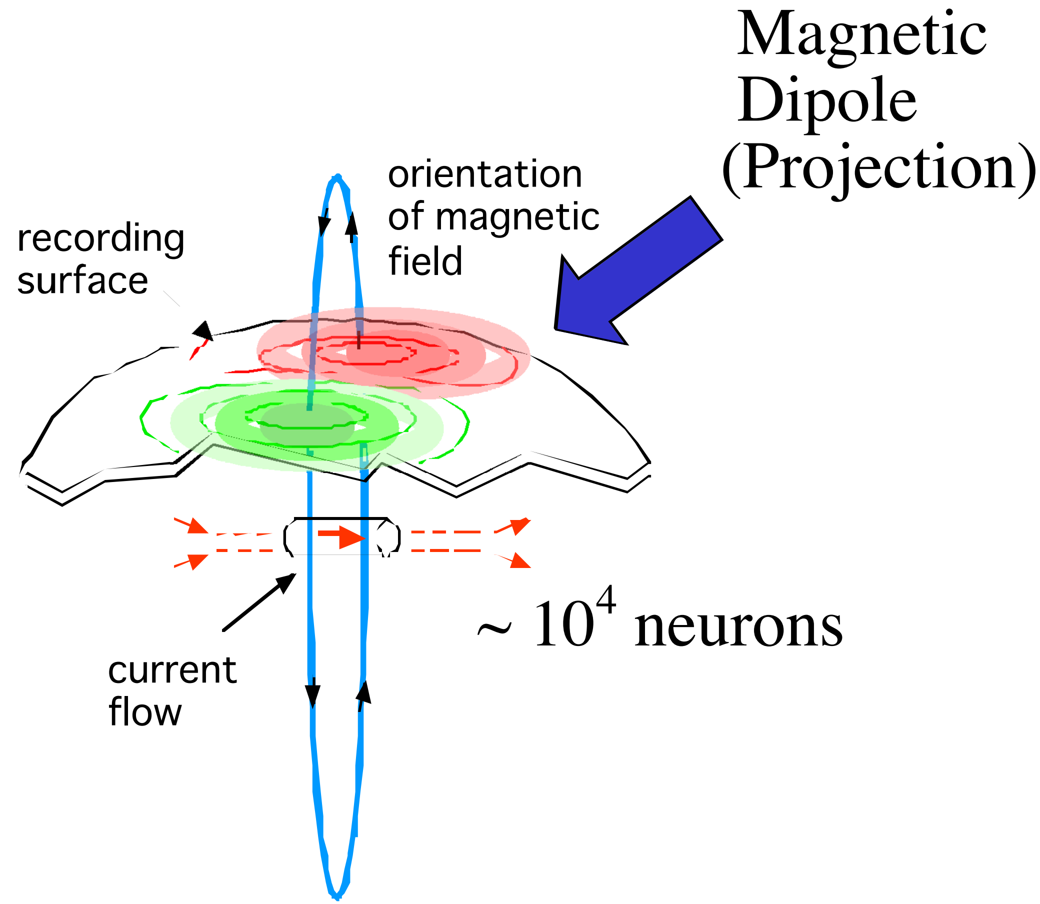
Neural Activity = Neural Current





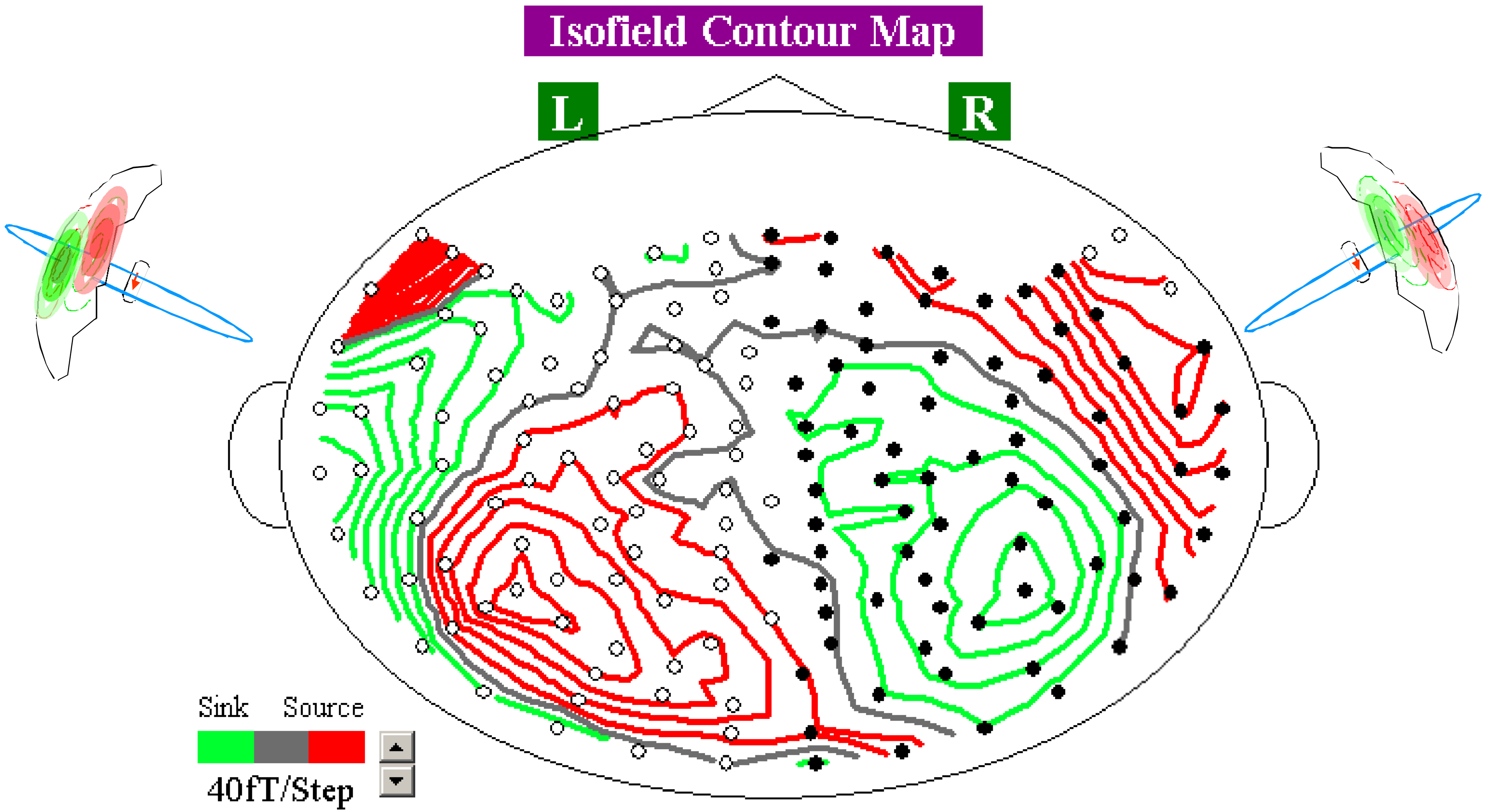
MEG Magnetic Signal





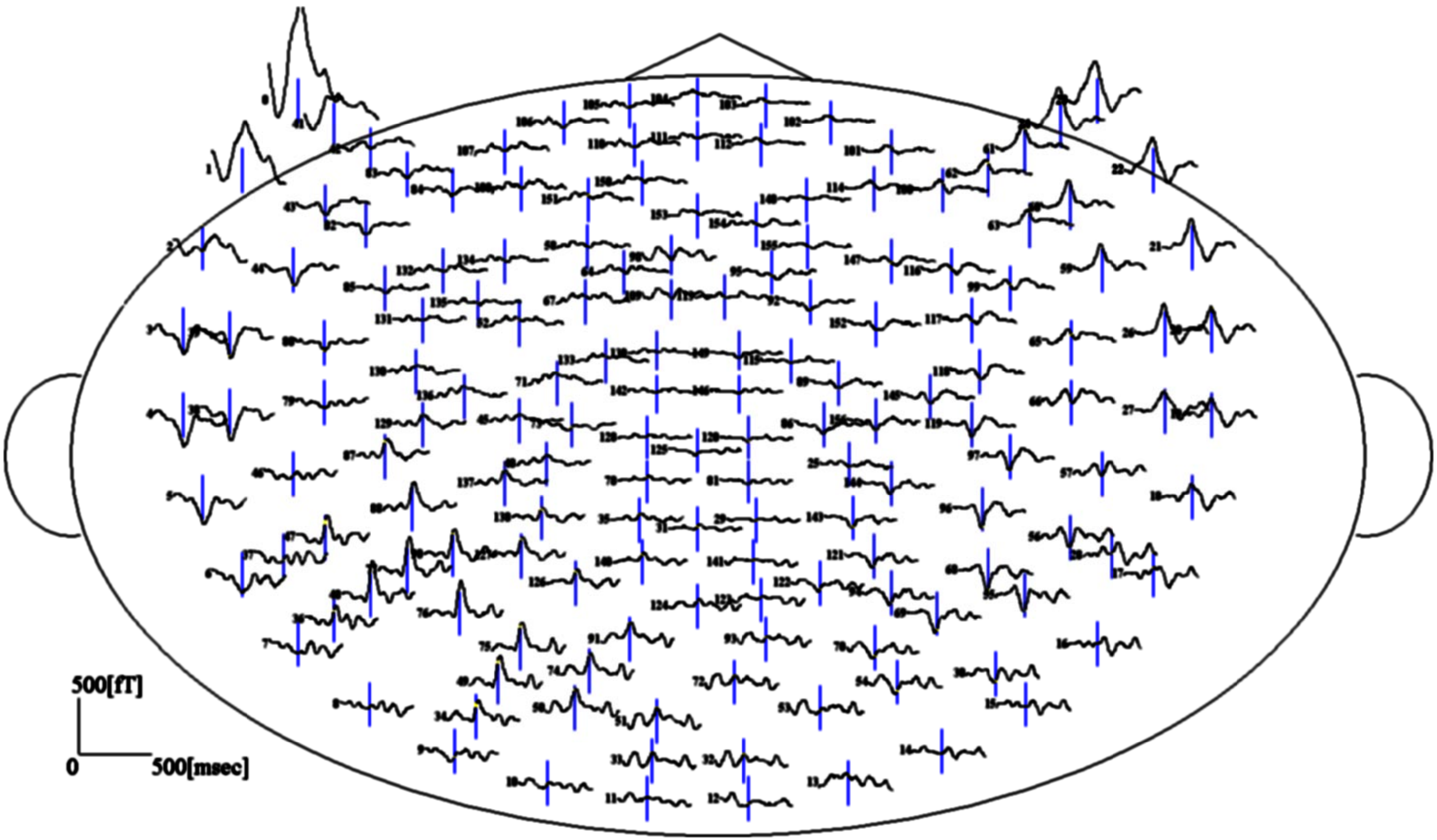
Non-invasive
Direct electrophysiological
measurement (not hemodynamic)

MEG Response



Time = 98.00[msec]

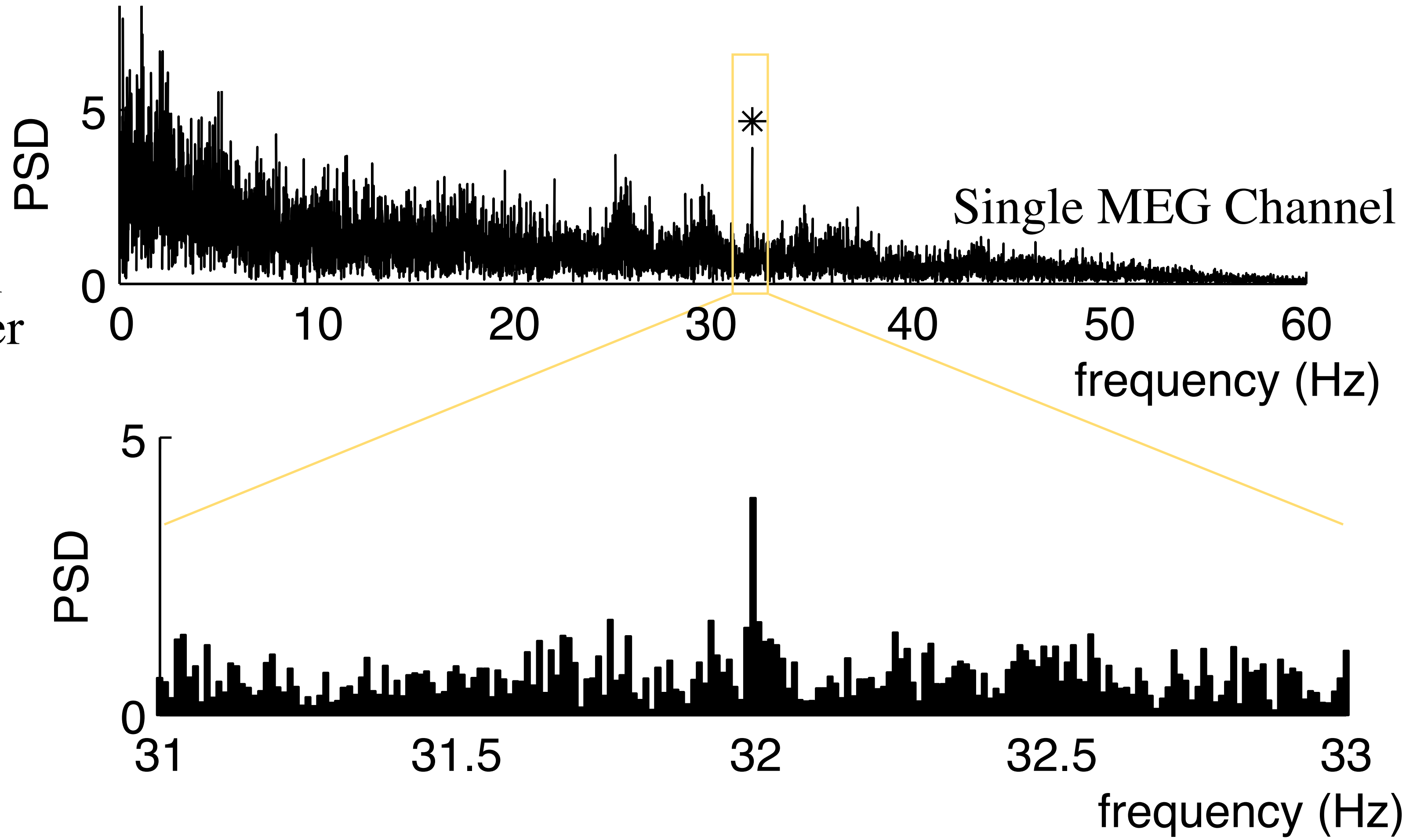
MEG Response



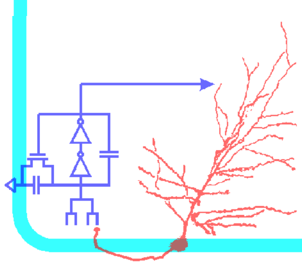
Frequency Response

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

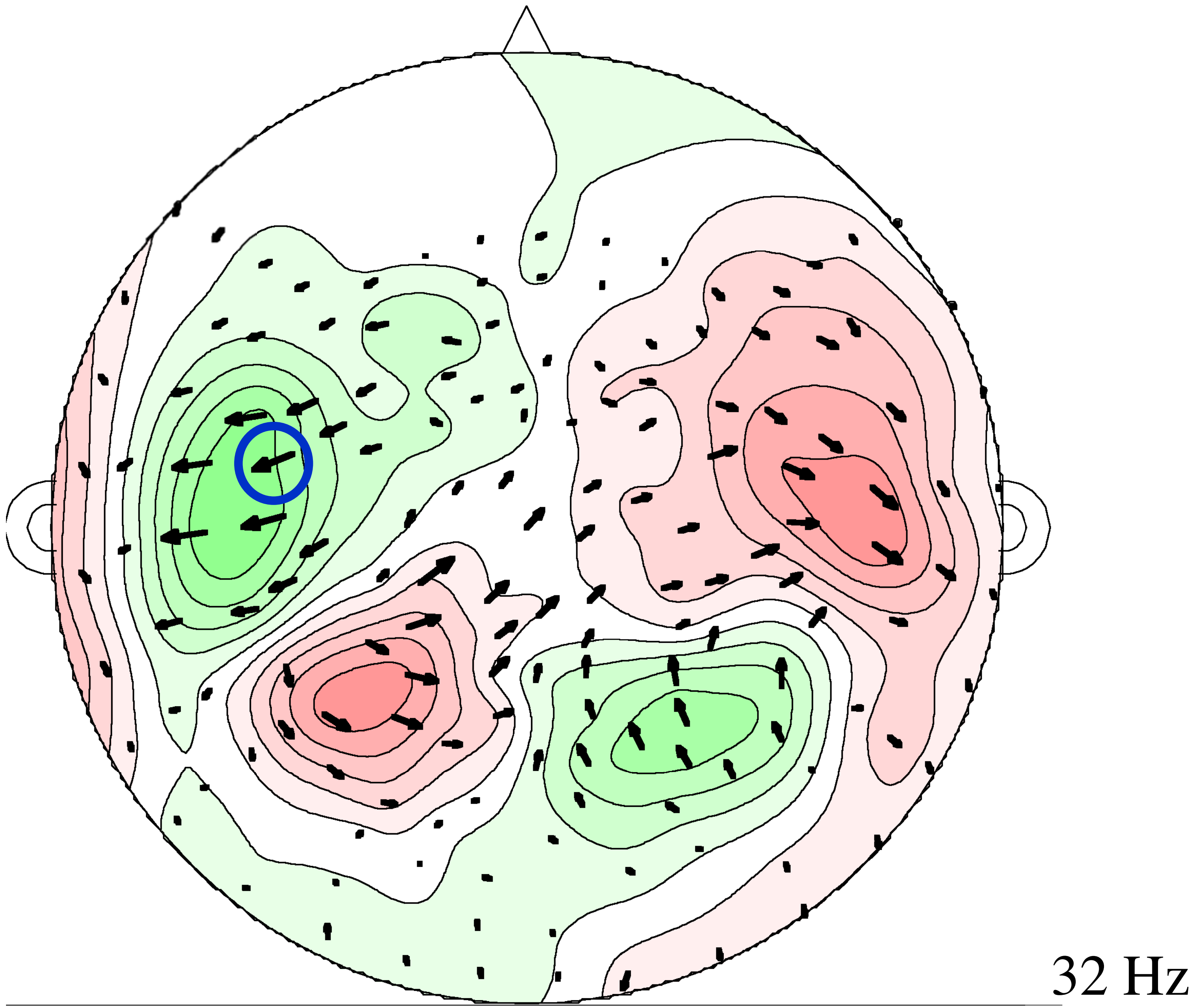
32 Hz Modulation
400 Hz tone carrier
100 trials @ 1 s
(concatenated)



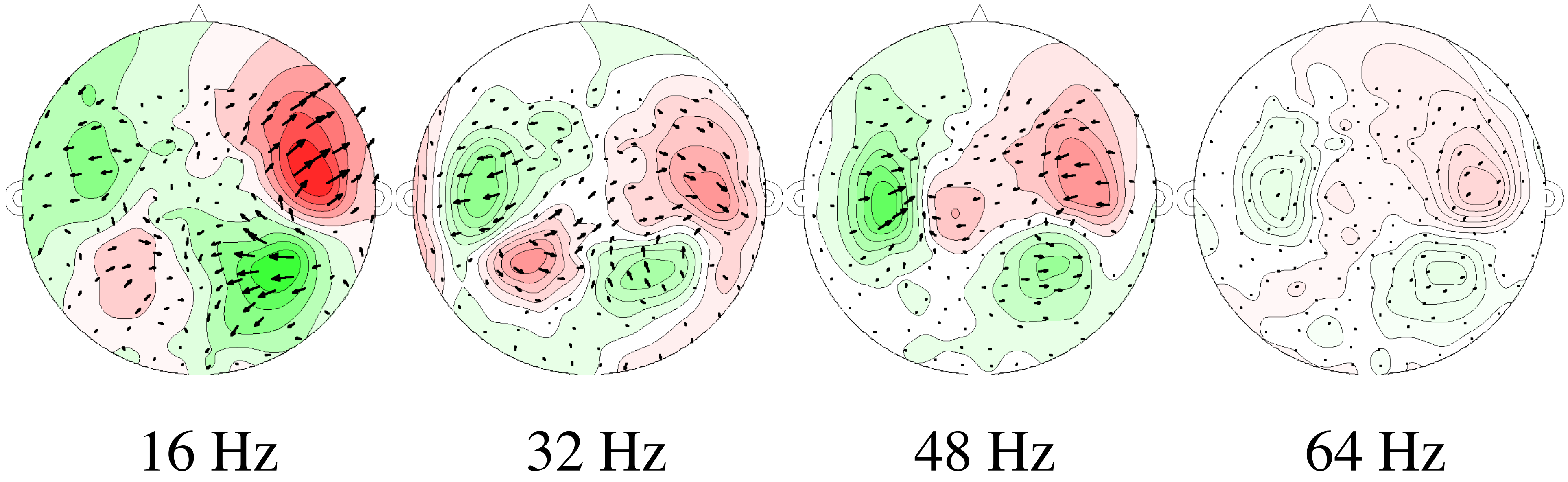
Extremely Precise Phase-Locking: 0.01 Hz
No trial-to-trial jitter



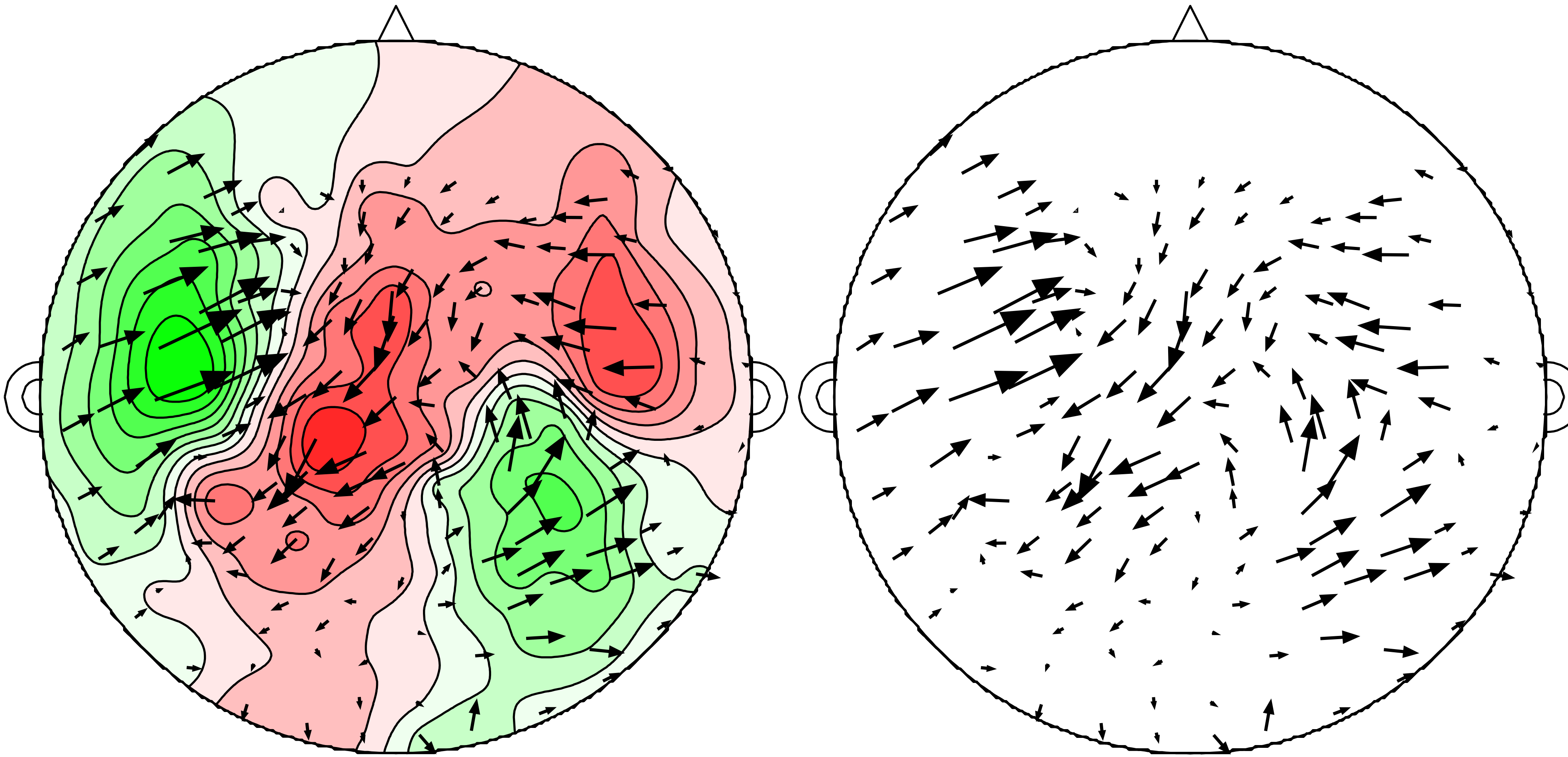
Whole Head Steady State Response



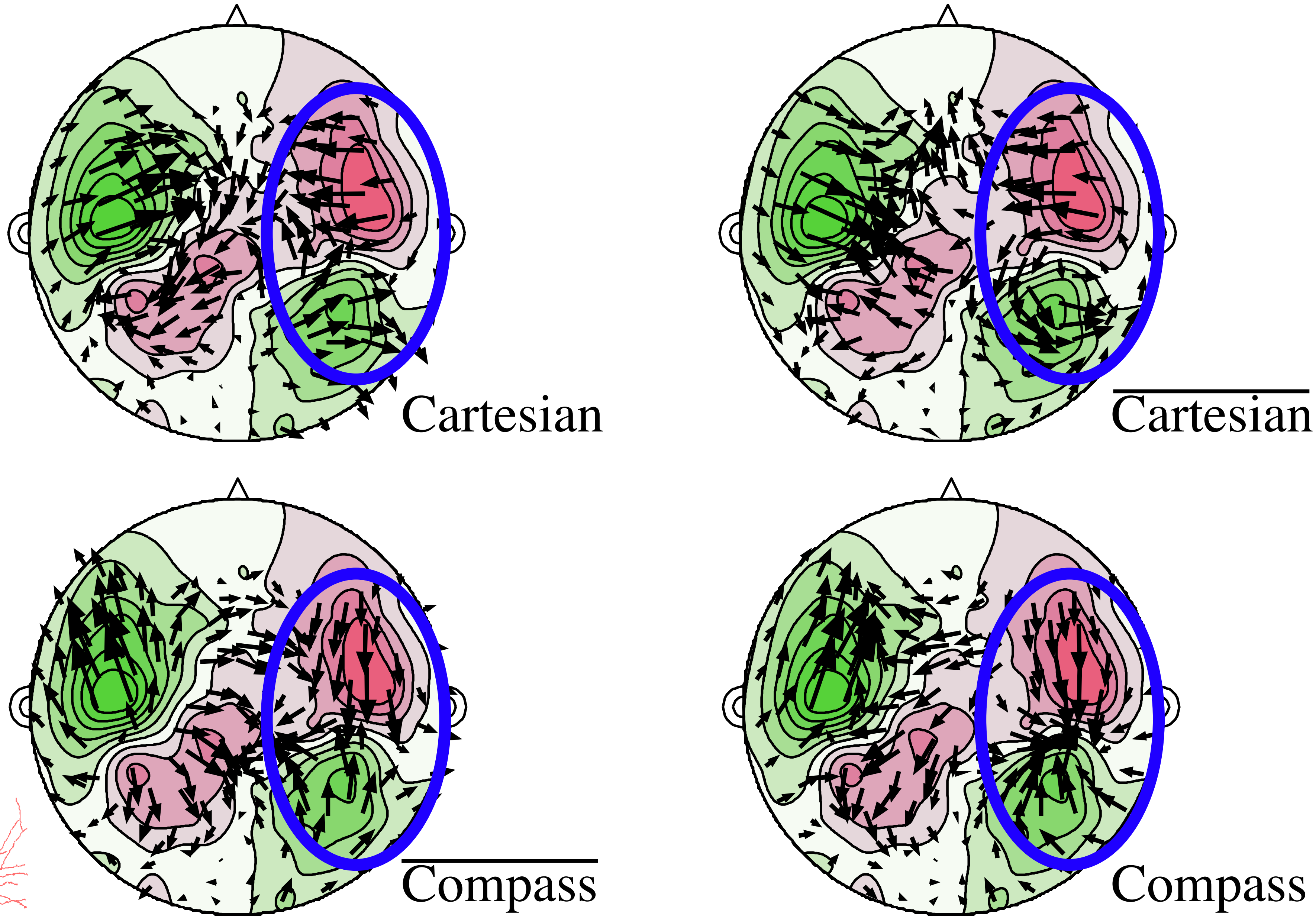
Whole Head Transfer Function



Complex Magnetic Field

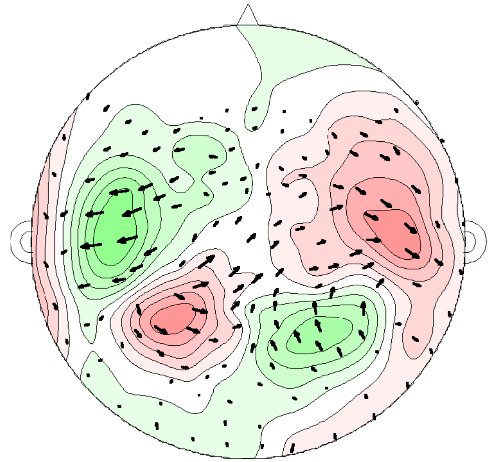


Phase Conventions

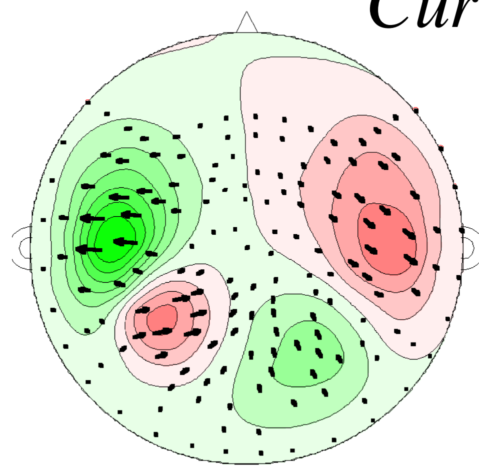


Current–Equivalent Dipoles

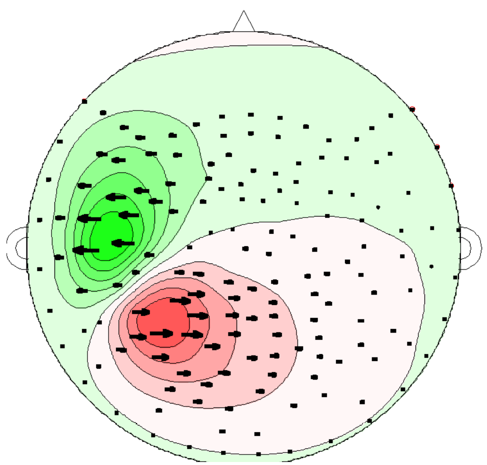
Raw Data



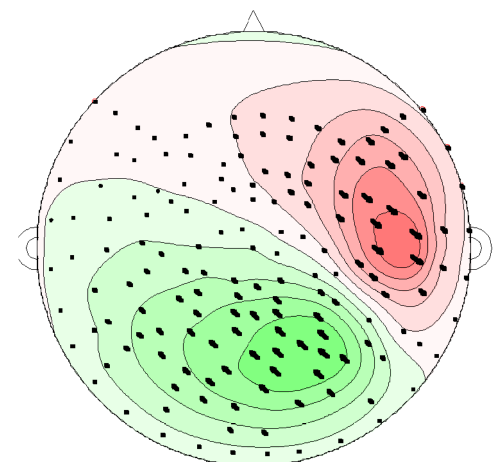
Current Dipoles Complex Too!



Two Dipole Fit



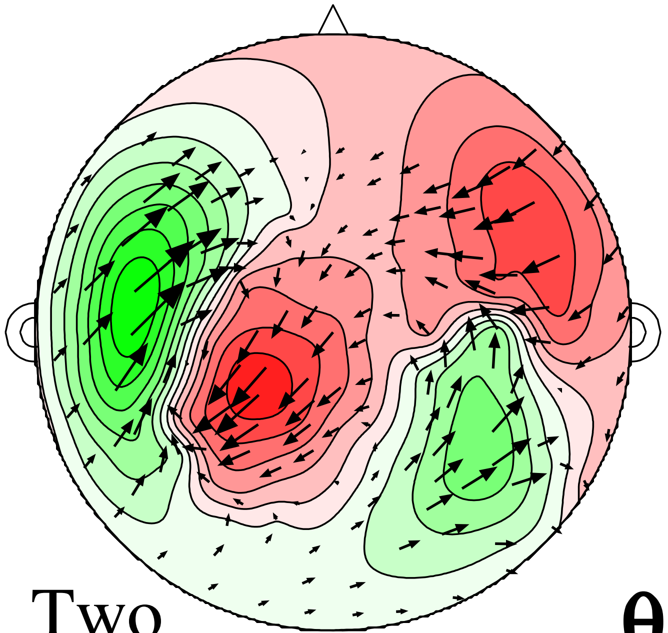
Left Dipole



Right Dipole

32 Hz

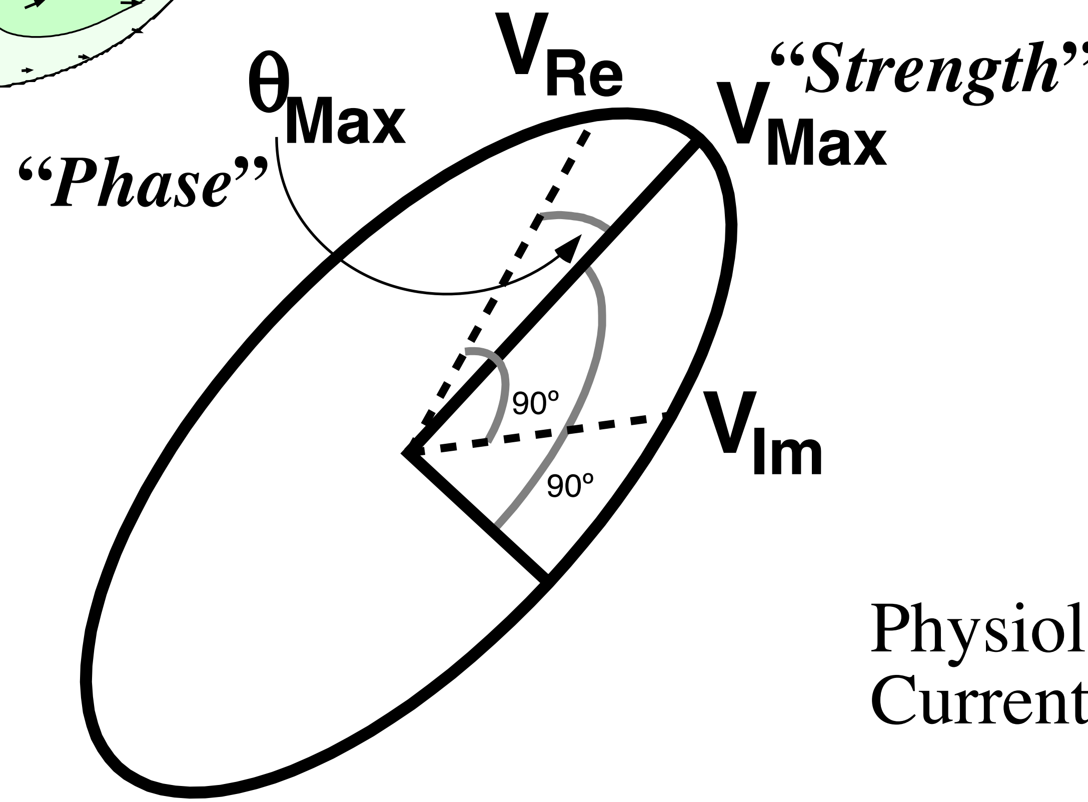
Complex Equivalent–Current Dipoles



Two Dipole Fit

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

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



“*Sharpness*”

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

$$0 < \eta < 1$$

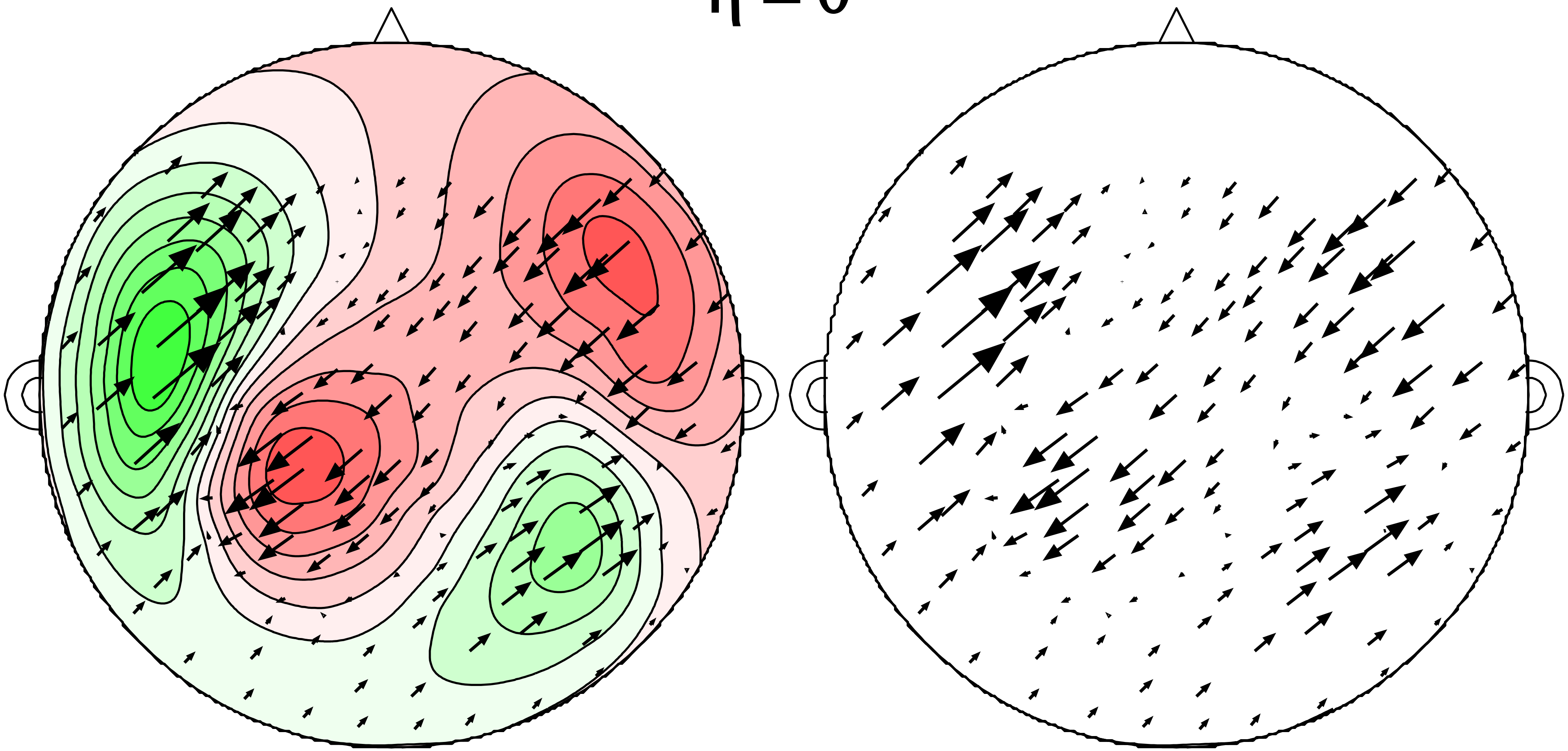
$\hat{V}_{Max}, \hat{V}_{Min}$

Orientations

Physiologically Simple Current Sources: $\eta = 0$

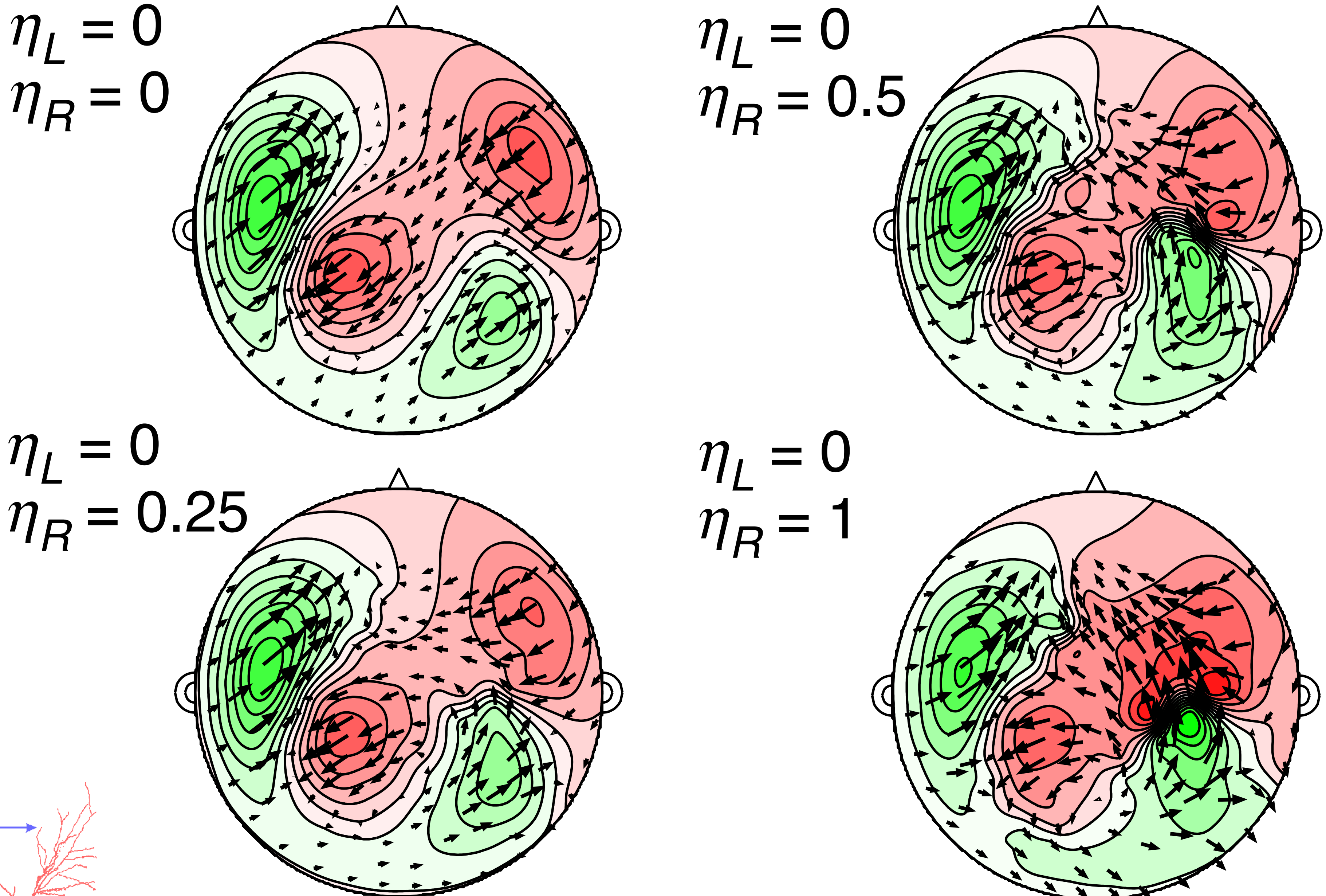
Single Orientation Current Sources

$\eta = 0$



Simulated Sharpness

Compound/Effective Current Sources



Summary

- Fully Complex MEG necessary
  - Complex Magnetic Flux
  - Generated by Complex Neural Currents
- Complex Neural Current Sources
  - Six Degrees of Freedom:
  - Orientation (2), Strength, Phase, Sharpness, Minor orientation (1)
  - Sharpness ➡ Compound Neural Source

Simon, J. Z. and Y. Wang (2005) *Fully Complex Magnetoencephalography*, J. Neurosci. Methods. 149(1), 64-73.

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Thank You

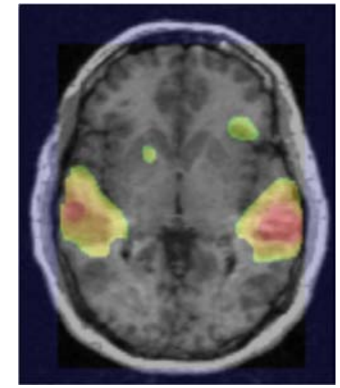
Functional Imaging

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

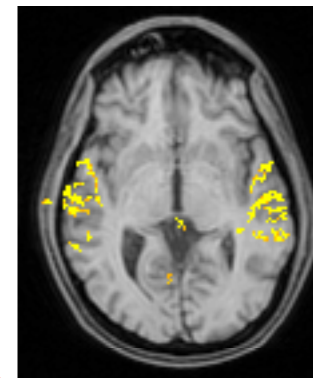
Hemodynamic techniques

Positron emission tomography
PET

Functional magnetic resonance imaging
fMRI



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

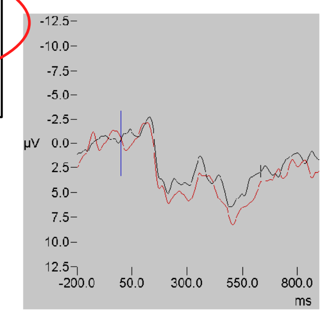


PET, EEG require across-subject averaging

fMRI and MEG can capture effects in single subjects

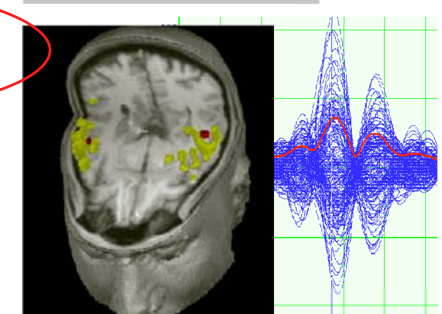
Electromagnetic techniques

Electroencephalography
EEG

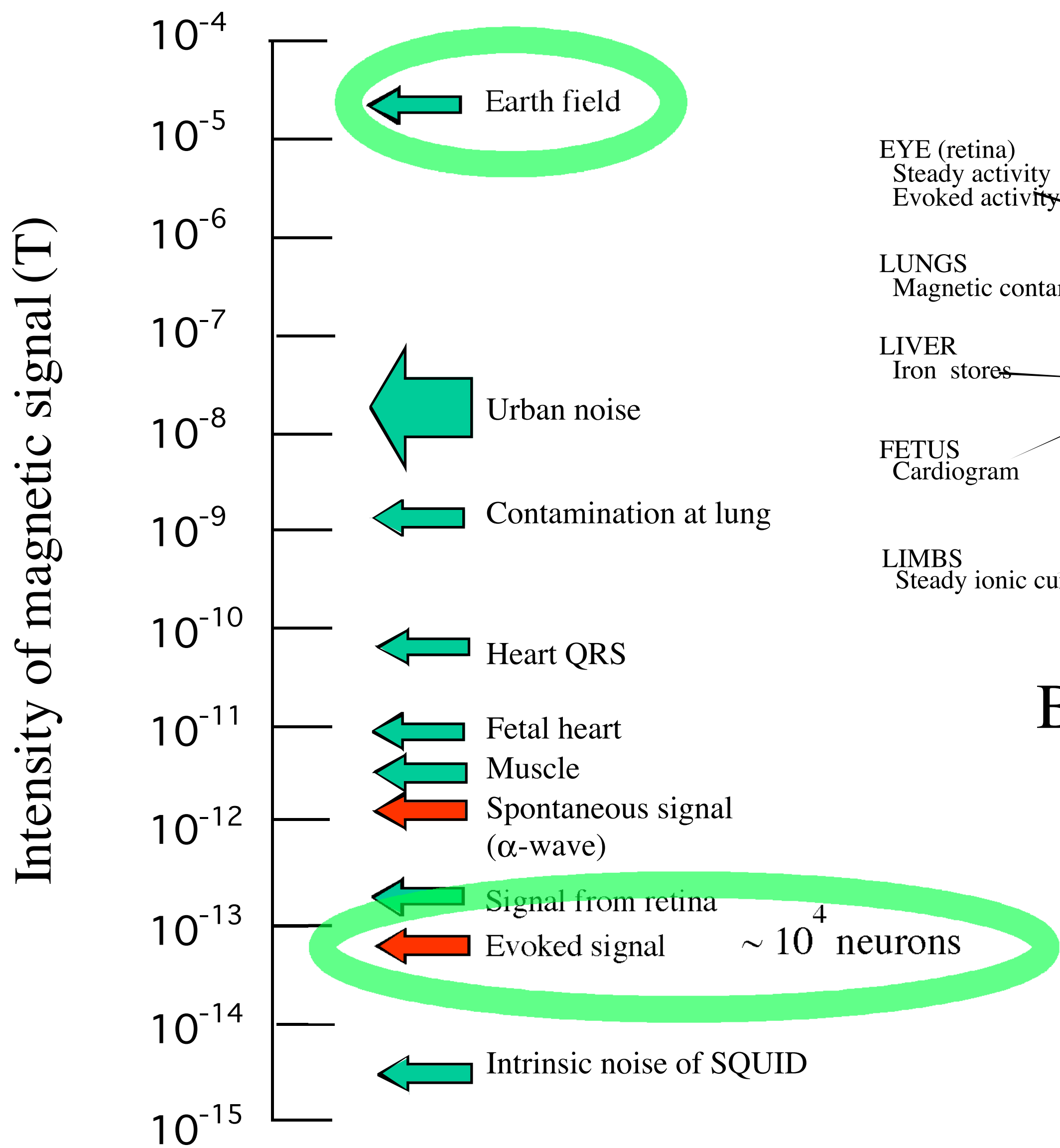


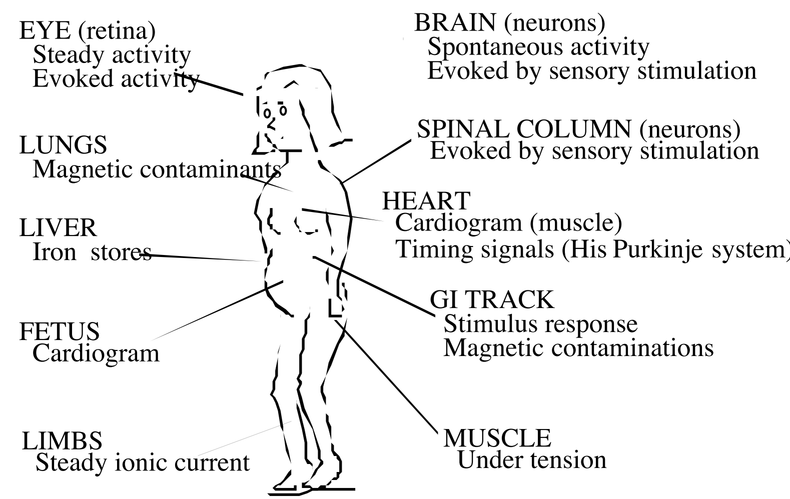
Poor spatial resolution
(~ 1 cm)
Excellent *temporal resolution*
(~ 1 ms)

Magnetoencephalography
MEG



Magnetic Field Strengths

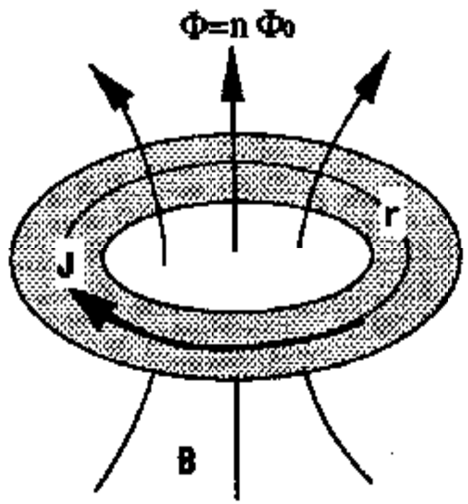




Biomagnetism

Magnetic Flux Detectors

Superconductivity →
Magnetic flux quantization →
Josephson Effect →
SQUID = Superconducting Quantum
Interference Device

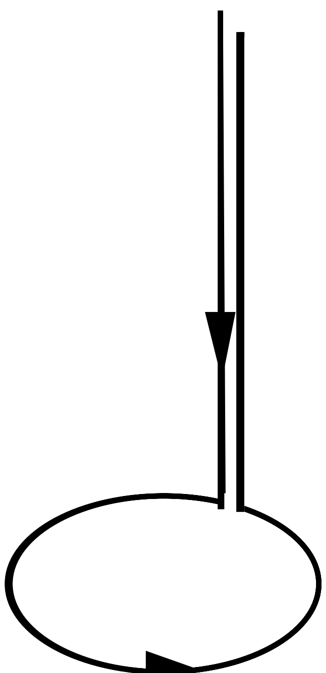


$$\Phi = n \frac{h}{2\,e} = n\,\Phi_0$$

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

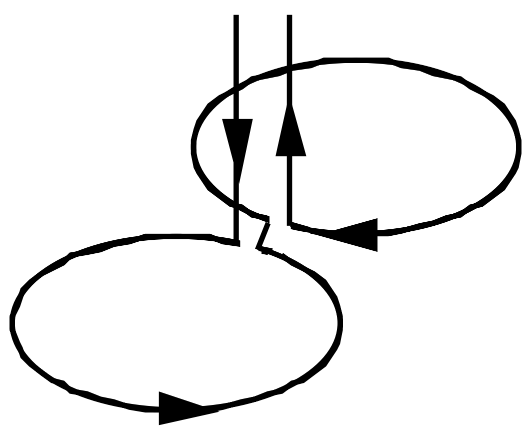
Sensor Configurations

SQUID Magnetometer

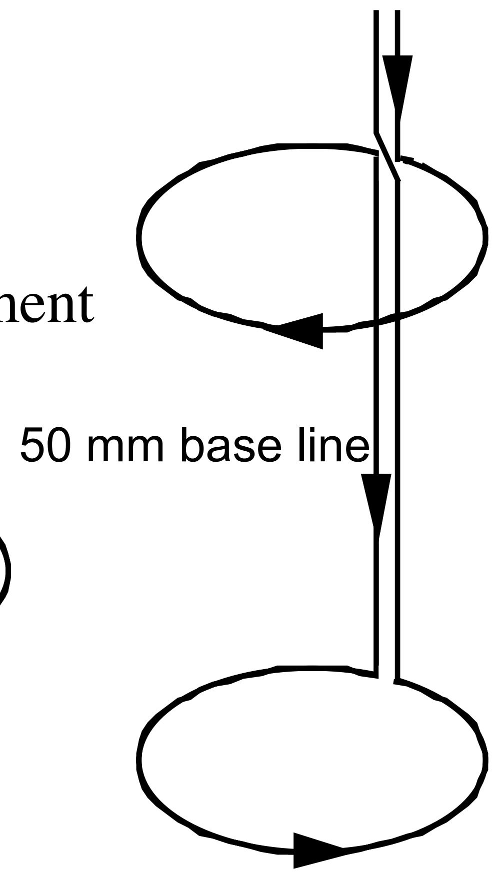


SQUID Gradiometer

Noise reduction from
Differential measurement



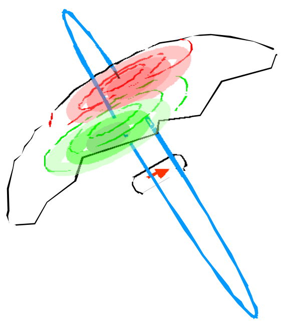
Planar type



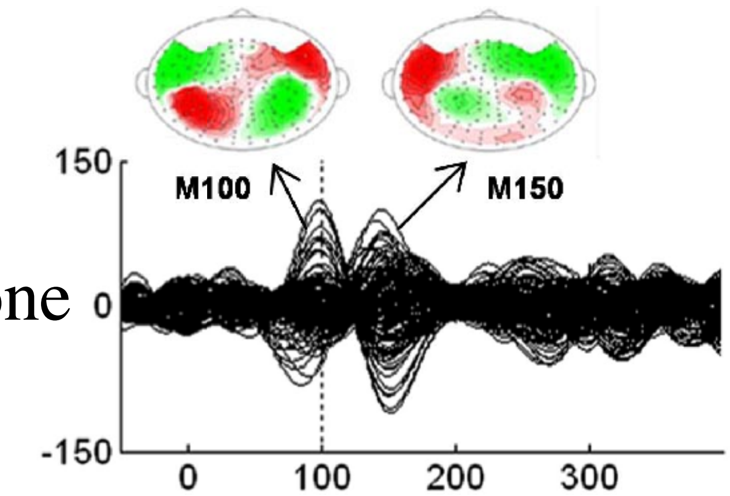
Axial type

Time Course of MEG Responses

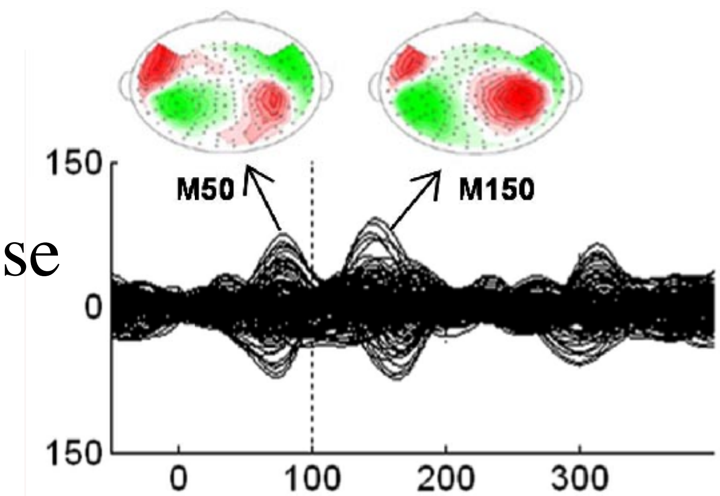
Evoked Responses
MEG Events Time-Locked
to Stimulus Event



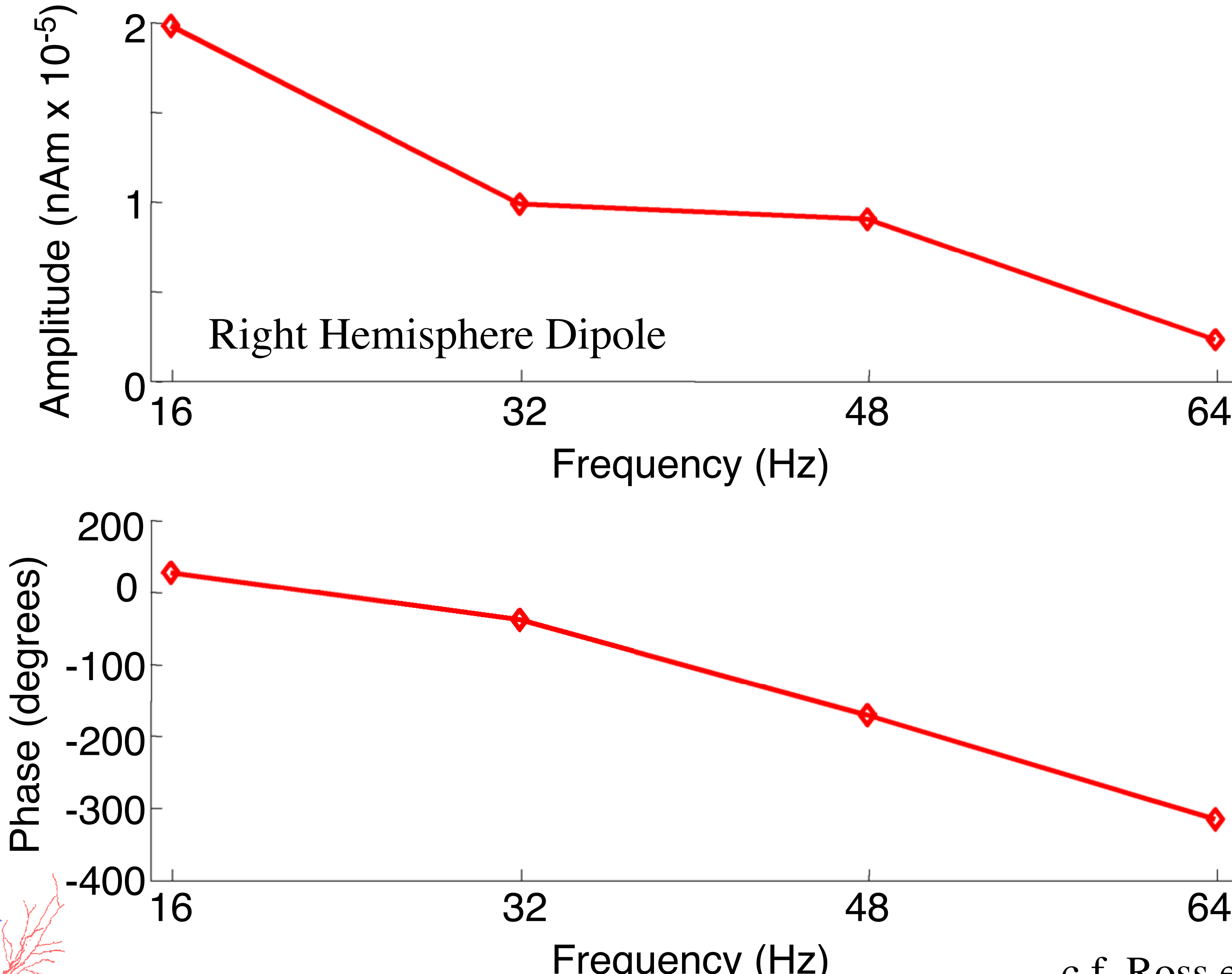
Pure Tone



Broadband Noise



Neural Modulation Transfer Function



c.f. Ross et al. (2000)