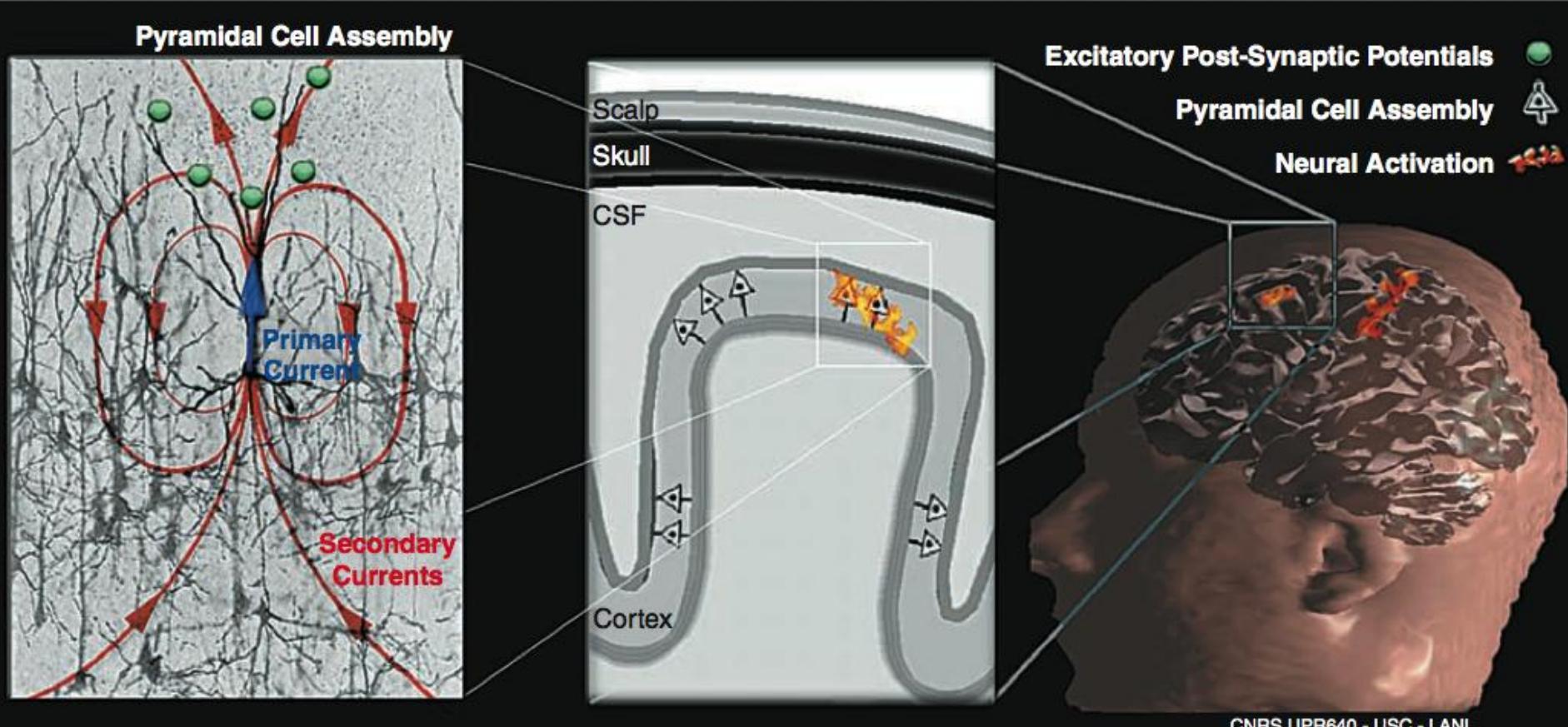


# EEG and MEG: functional brain imaging with high temporal resolution

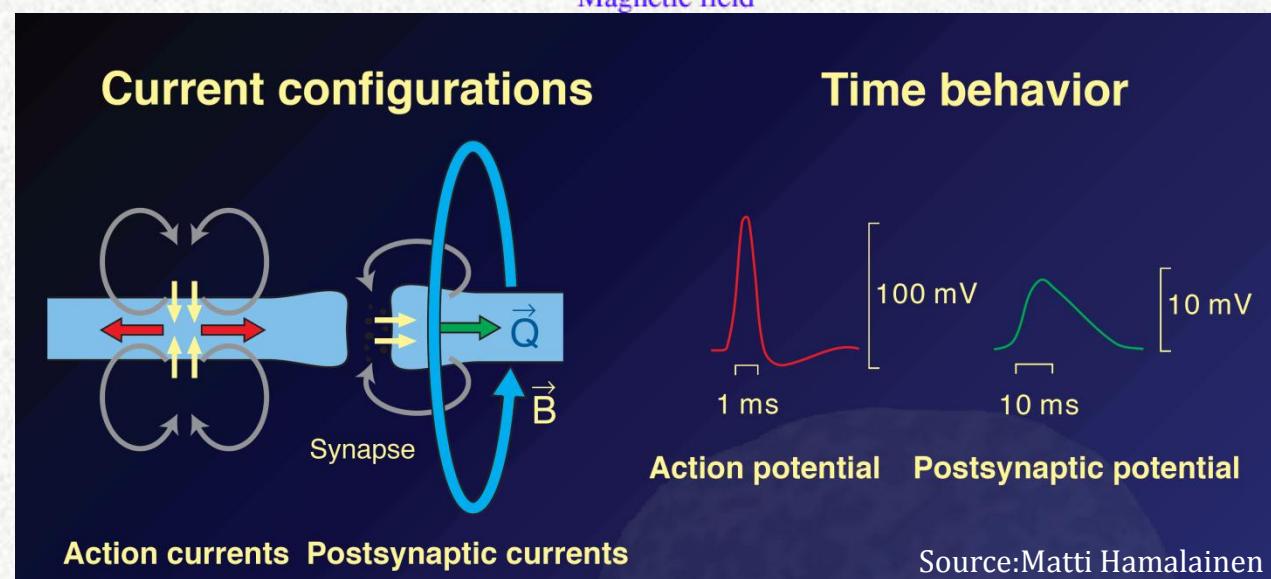
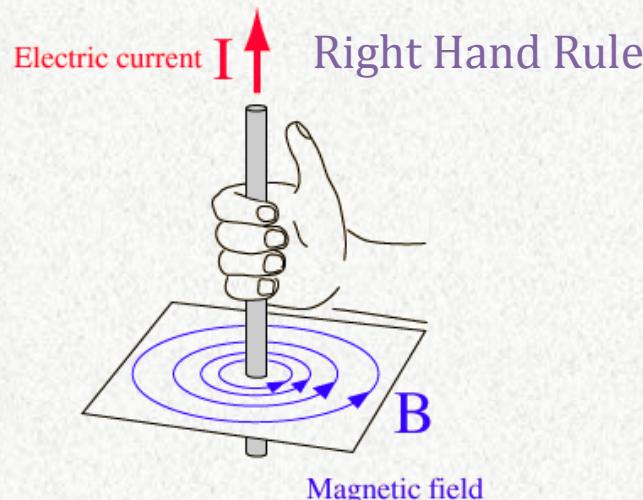
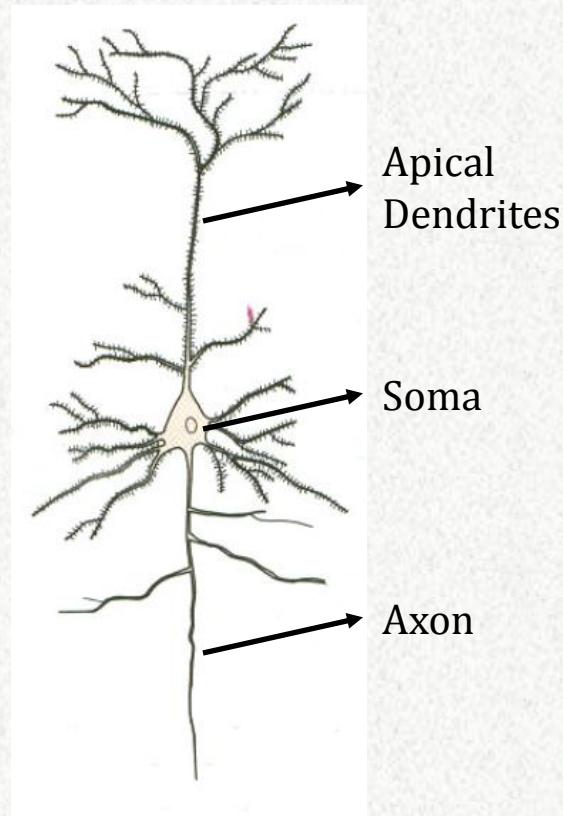
Syed Ashrafulla

# electrical signals in the brain



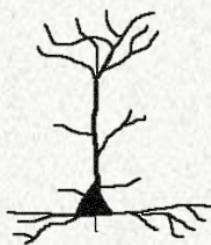
# recordable signals

Pyramidal Neuron



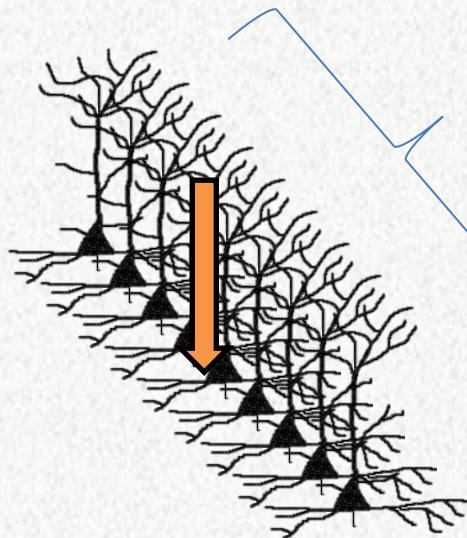
# measurable currents

- We can only measure assemblies of neurons.



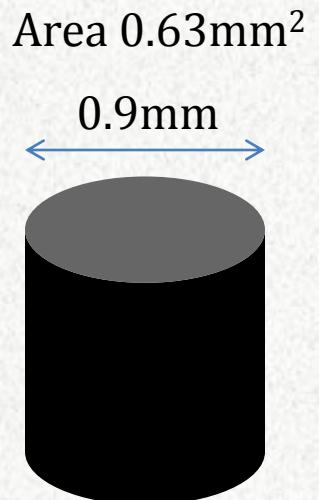
0.2pAm

Current dipole of  
cortical pyramidal cell



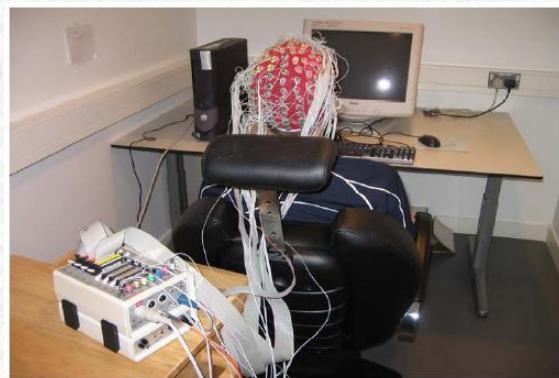
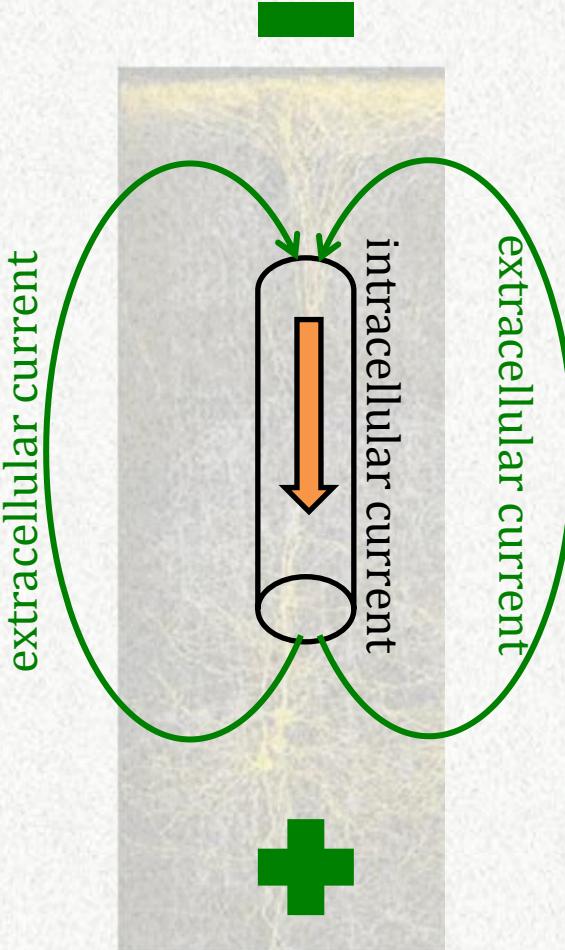
Weakest measurable cortical signal  
→ Model as one “dipole”

10nAm  
Or  
50,000  
synchronous  
cells

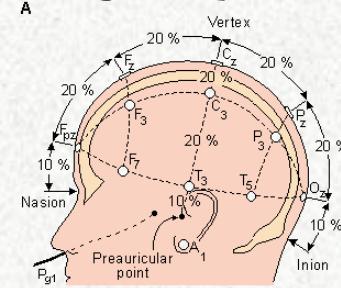


Cortical area

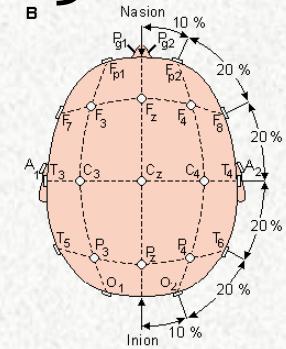
# electroencephalography (EEG)



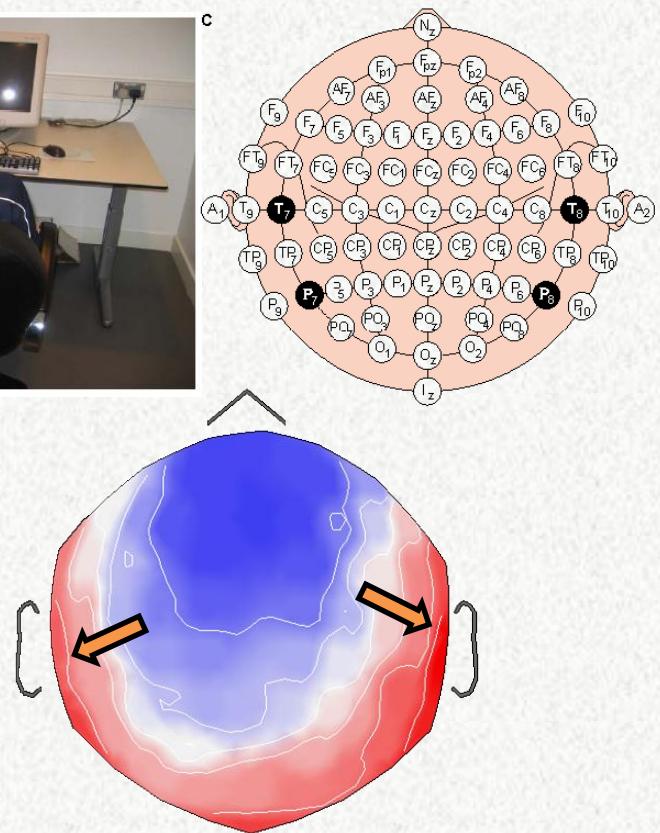
A



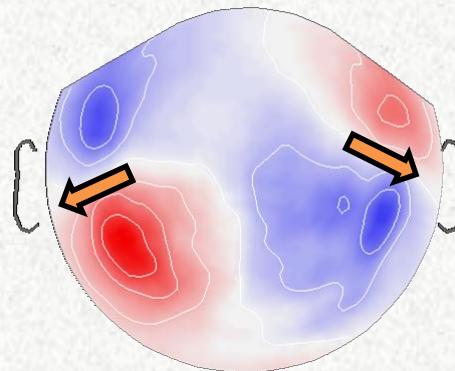
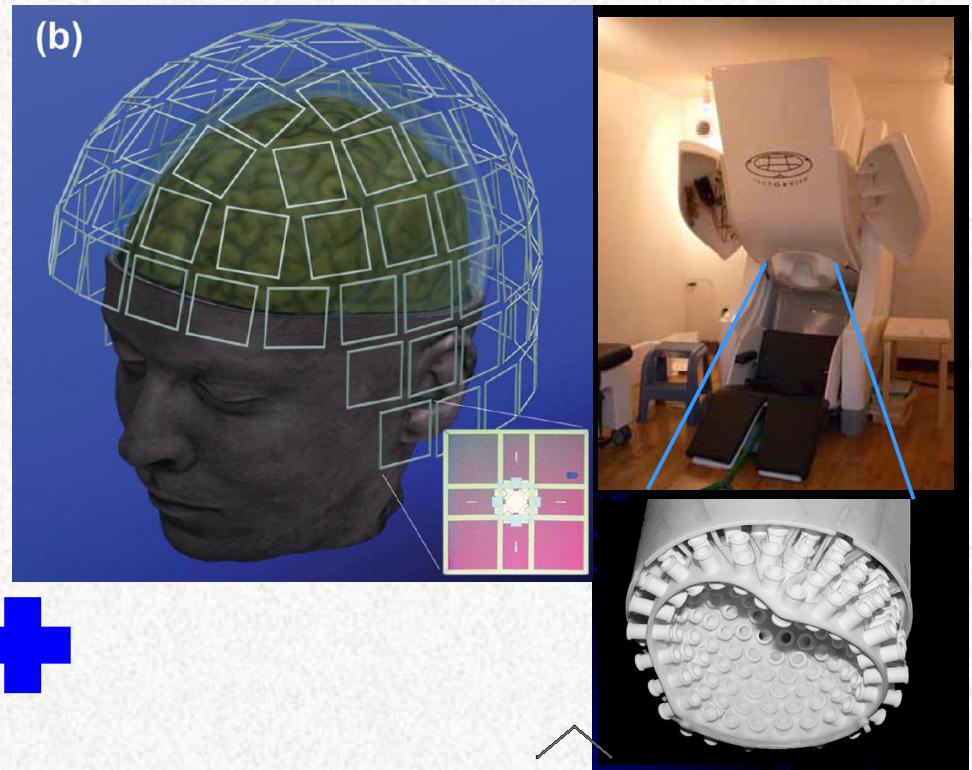
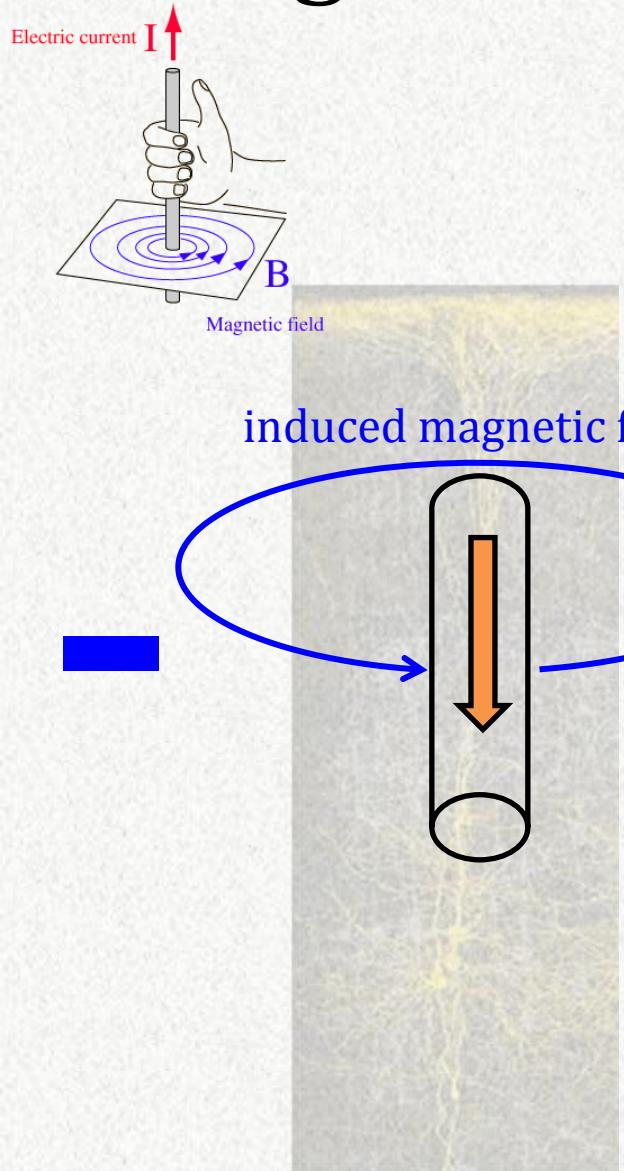
B



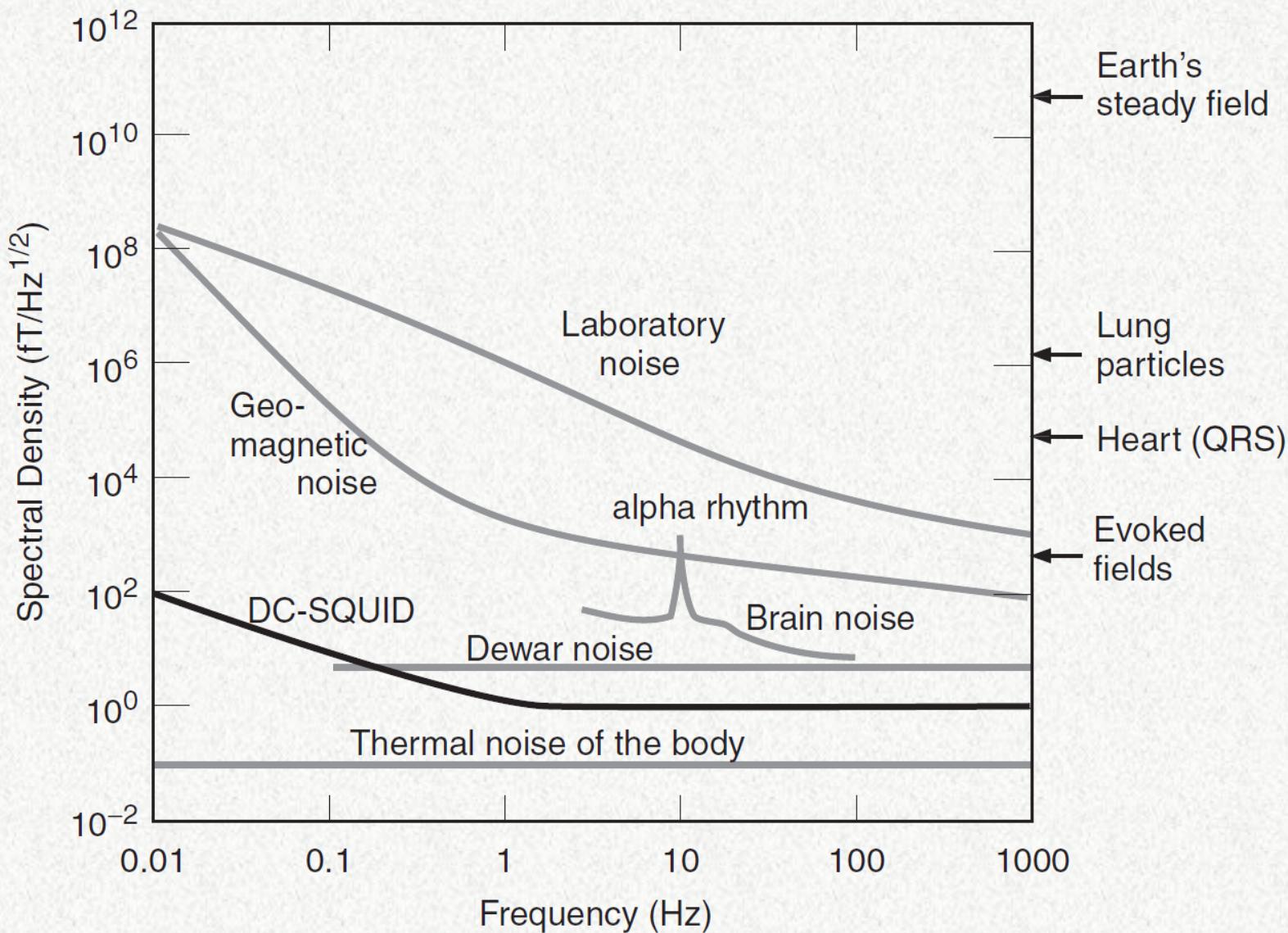
C



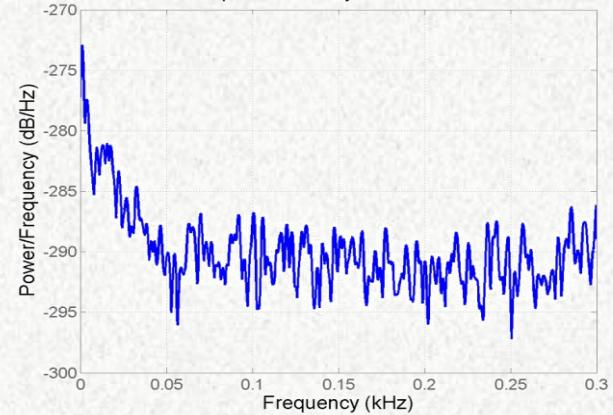
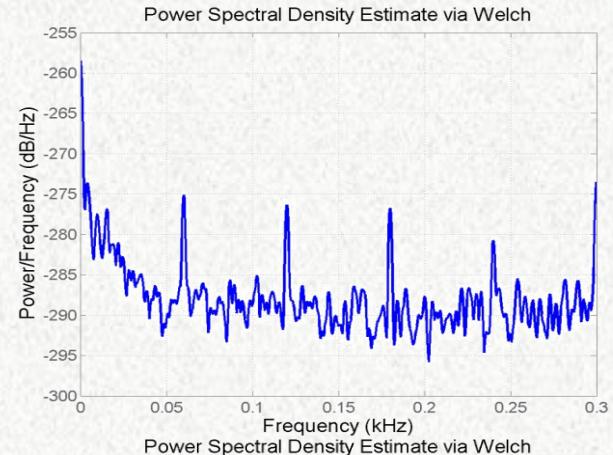
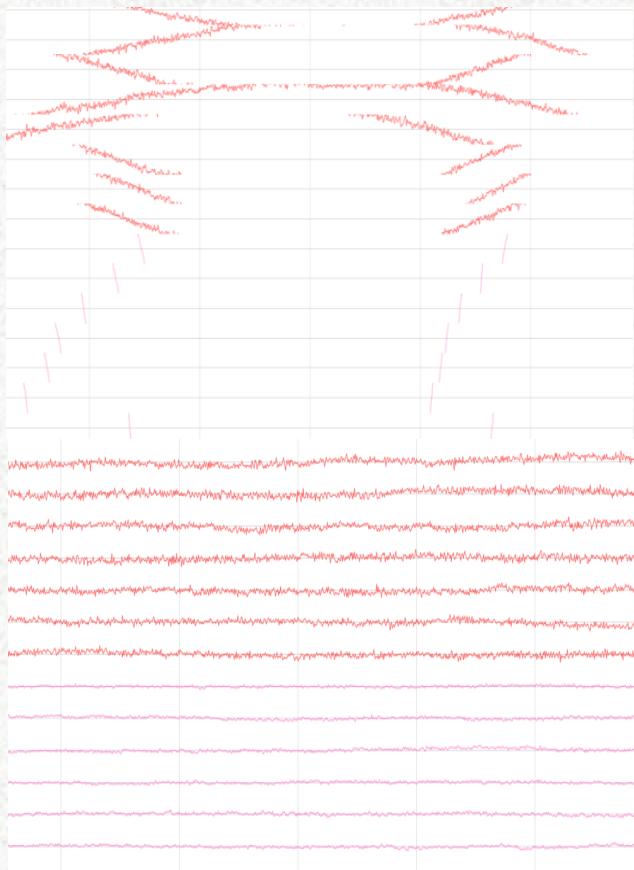
# magnetoencephalography (MEG)



# MEG signal strength

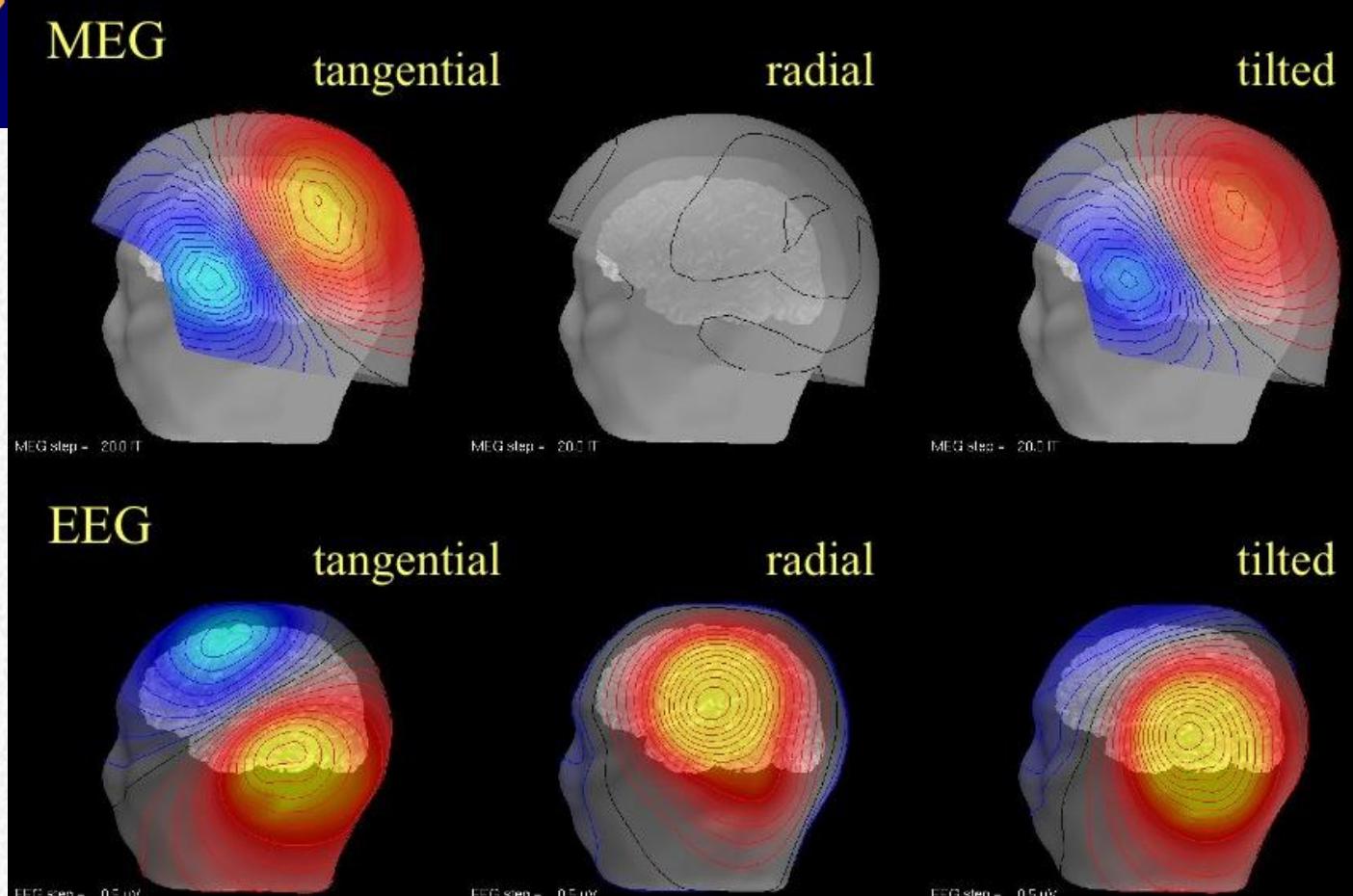
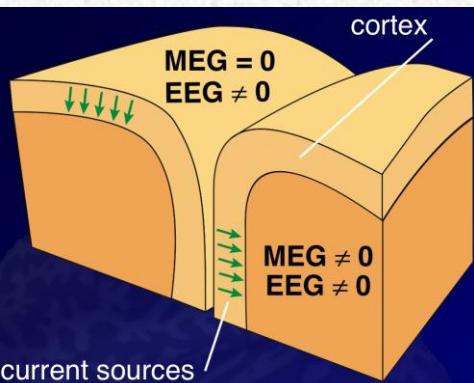


# MEG artifacts



- Use signal space projection and noise cancellation techniques in preprocessing.

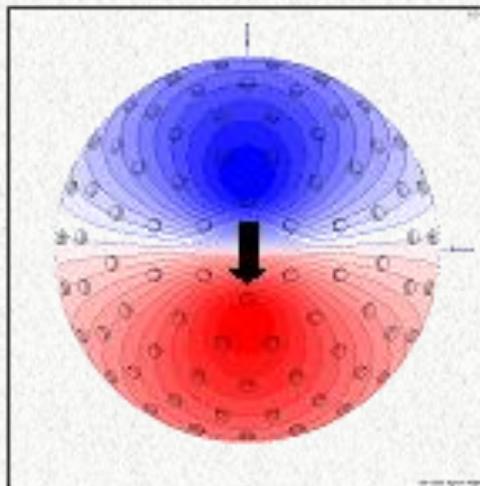
# what can/can't be seen



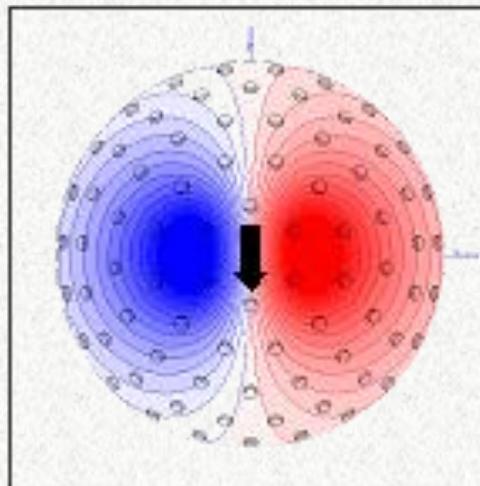
# what can/can't be seen

**8cm  
from  
centre**

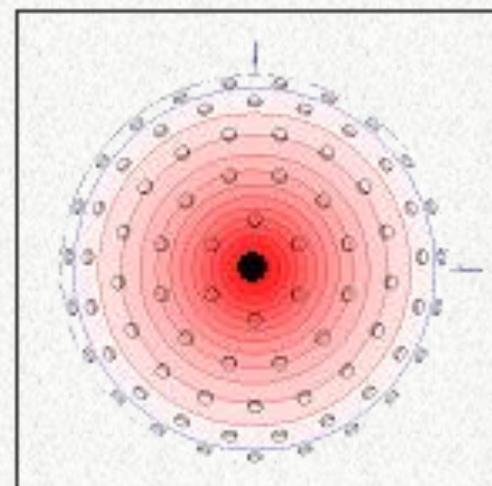
**EEG tangential**



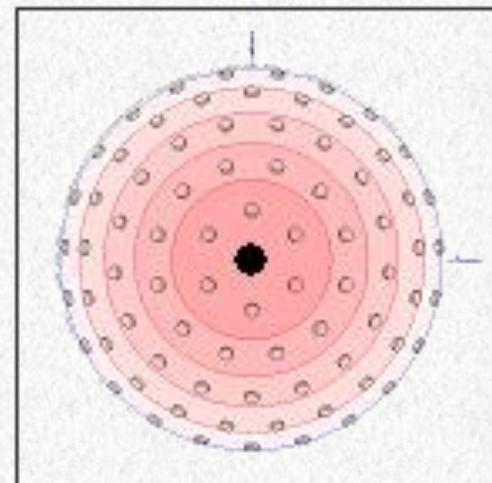
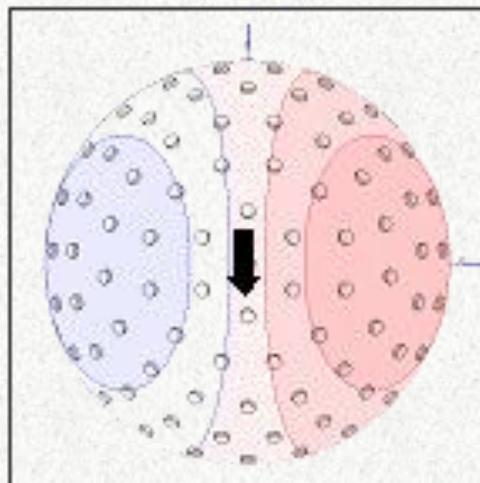
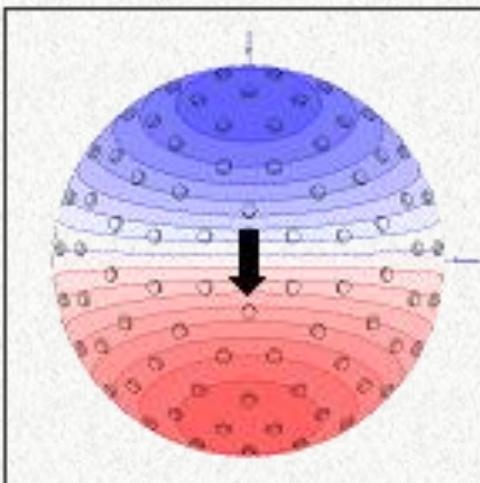
**MEG tangential**



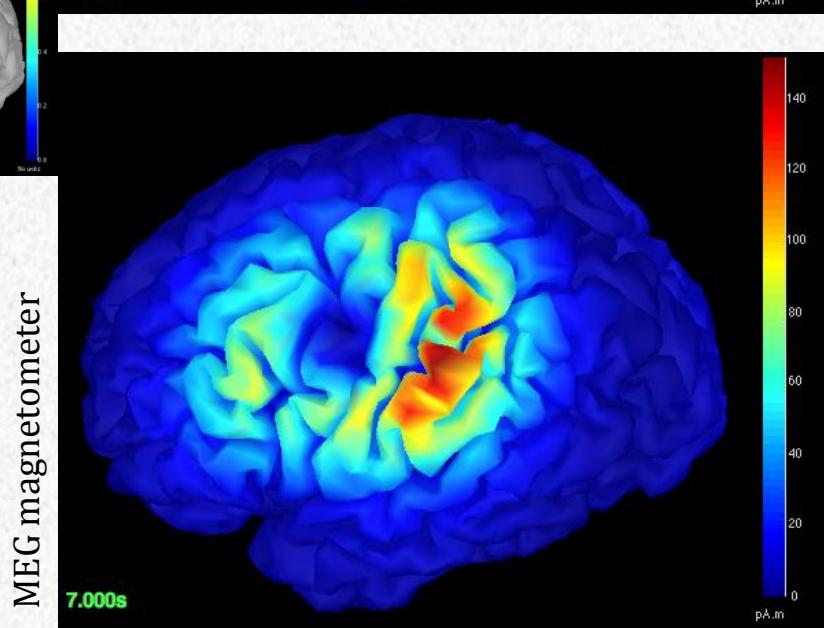
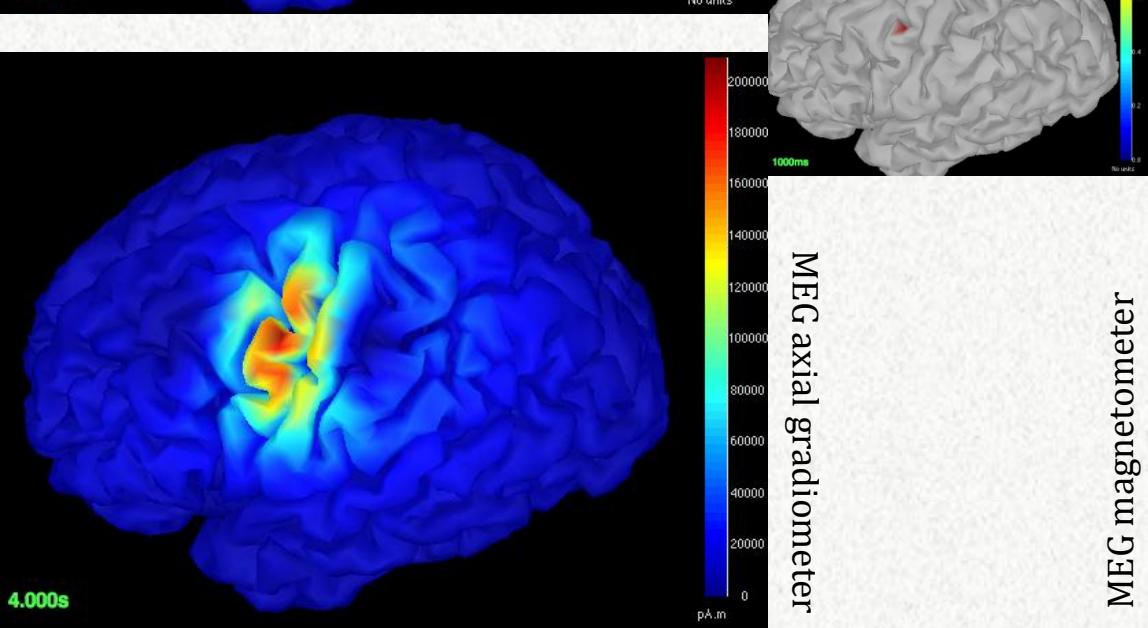
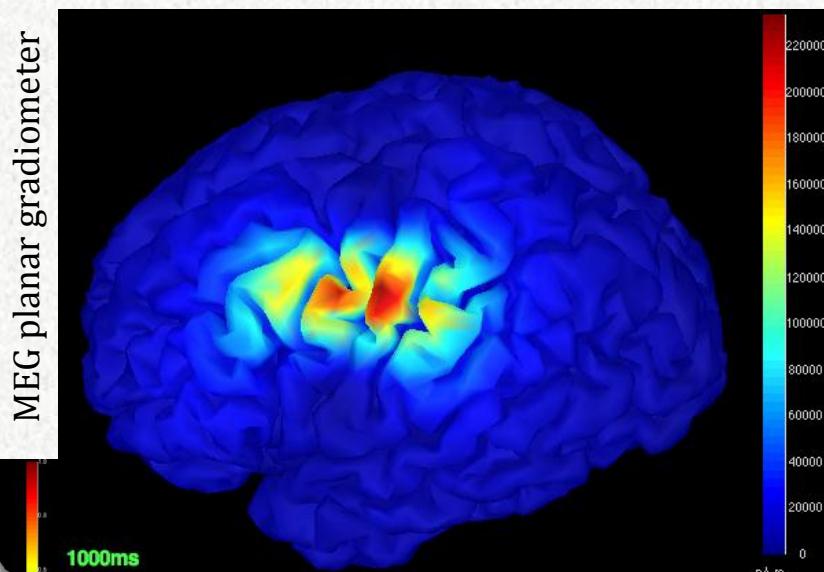
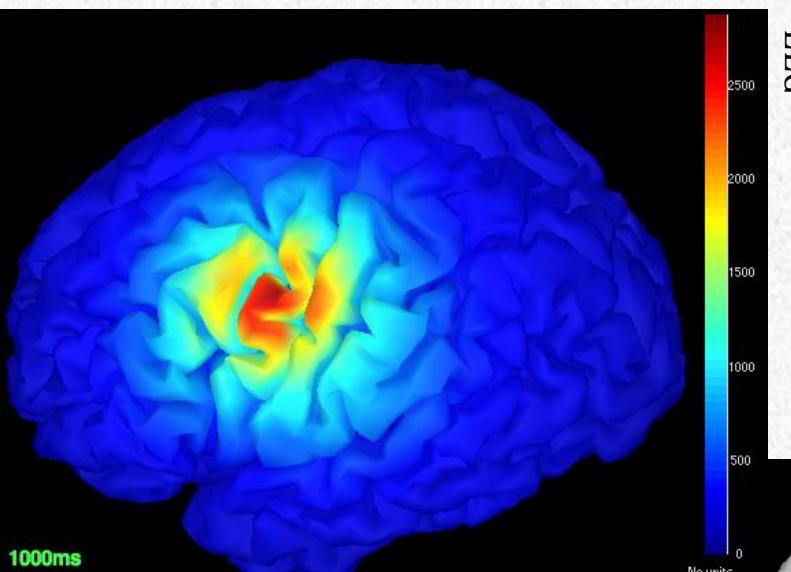
**EEG radial**



**4cm  
from  
centre**



# sensitivity profiles



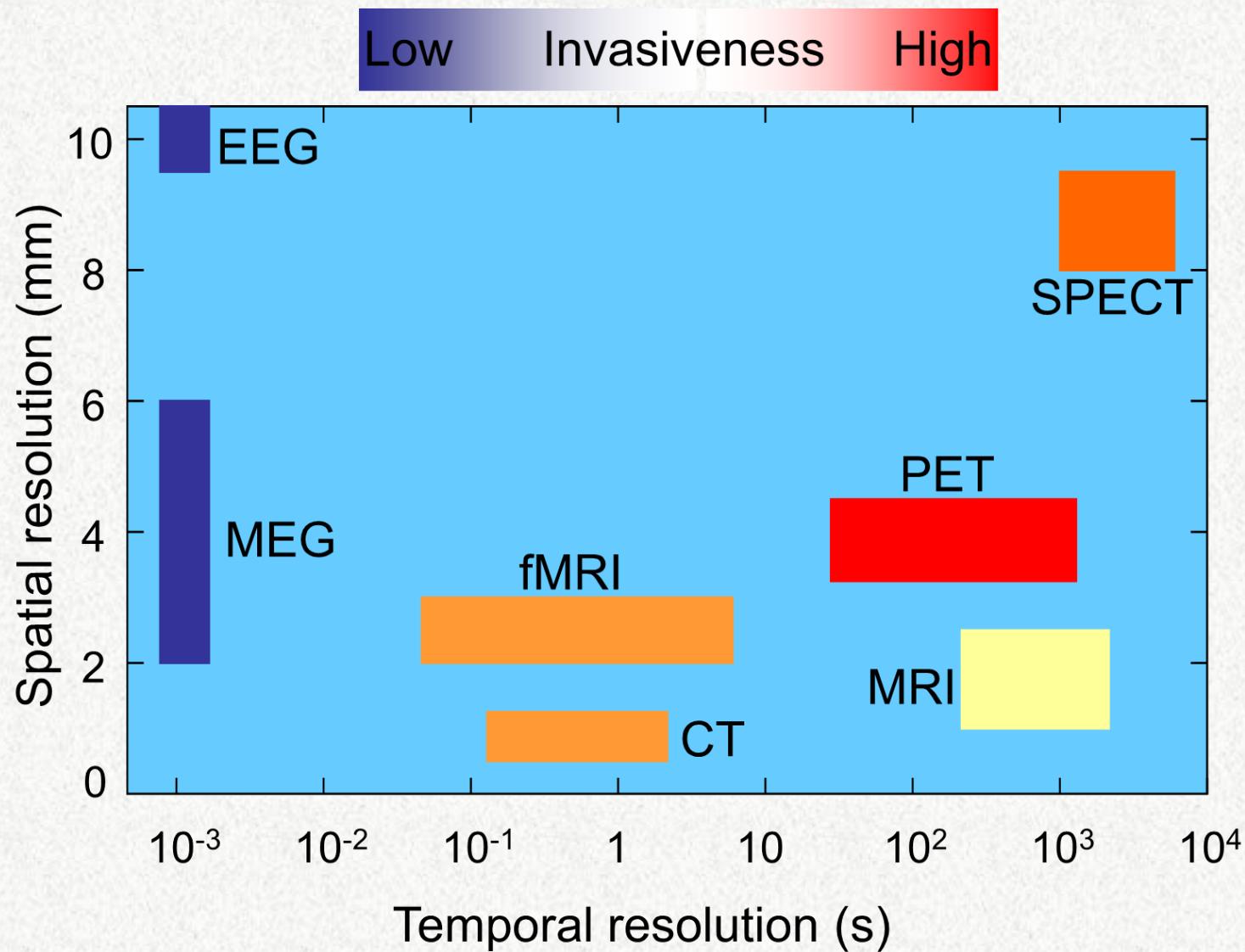
# EEG vs MEG

	<b>EEG</b>	<b>MEG</b>
Signal magnitude	10 mV (easy to detect)	10 fT, difficult to detect
Measurement	Secondary currents	Primary currents
Signal purity	Skull/scalp attenuation	Little effect of skull/scalp
Temporal Resolution	~ 1 ms	~ 1 ms
Spatial Localization	~ 1 cm	< 1 cm
Experimental Flexibility	Moves with subject	Stationary with subject
Dipole Orientation	Tangential & radial → Most sources are not fully radial	Only tangential

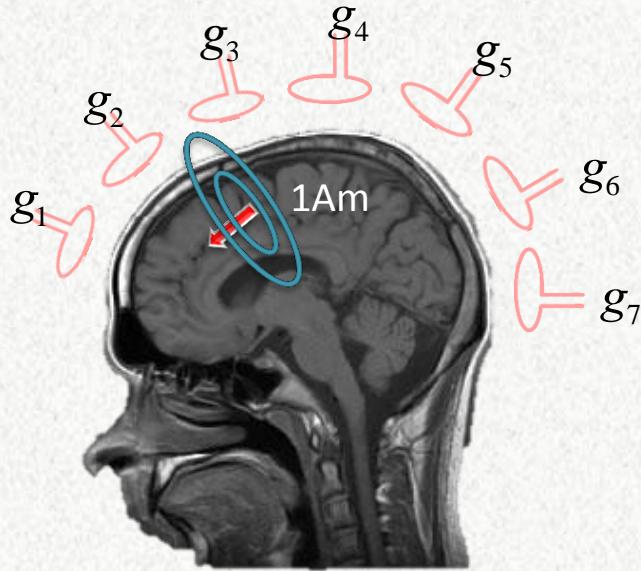
# EEG/MEG vs. fMRI

	<b>EEG/MEG</b>	<b>fMRI</b>
Temporal Resolution	~ 1 ms	~ 1 s
Signal Type	Direct (currents)	Indirect (BOLD)
Signal Reconstruction	Ill-posed inversion	Deconvolution
Spatial Localization	~ 1 cm	≈ 1 mm for high-T
Sensitivity depth	~ 4 cm	Whole-brain
Sensitivity profile	drops off as square of distance from sensor	
Signal orientation	Tangential (and radial) → Can cause signal cancellation	Agnostic

# resolution comparison

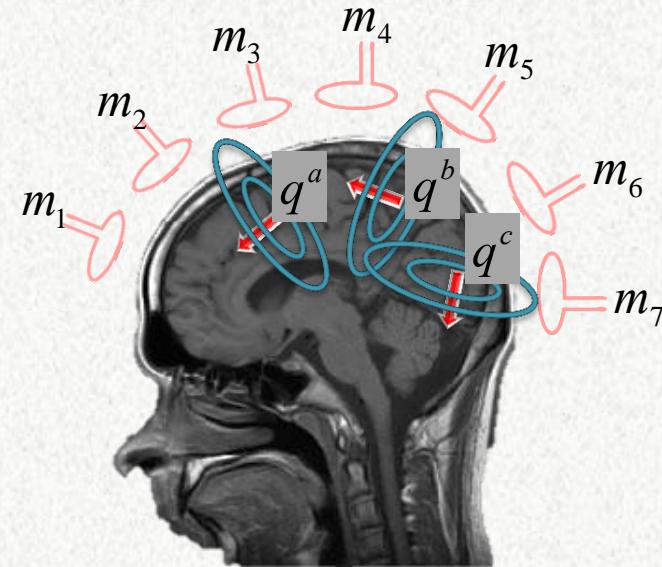


# modelling EEG/MEG recordings



$$m_1 = g_1 \cdot 1$$

$$m_2 = g_2 \cdot 1$$

 $\vdots$ 


$$m_1 = g_1^a \cdot q^a + g_1^b \cdot q^b + g_1^c \cdot q^c$$

$$m_2 = g_2^a \cdot q^a + g_2^b \cdot q^b + g_2^c \cdot q^c$$

 $\vdots$ 

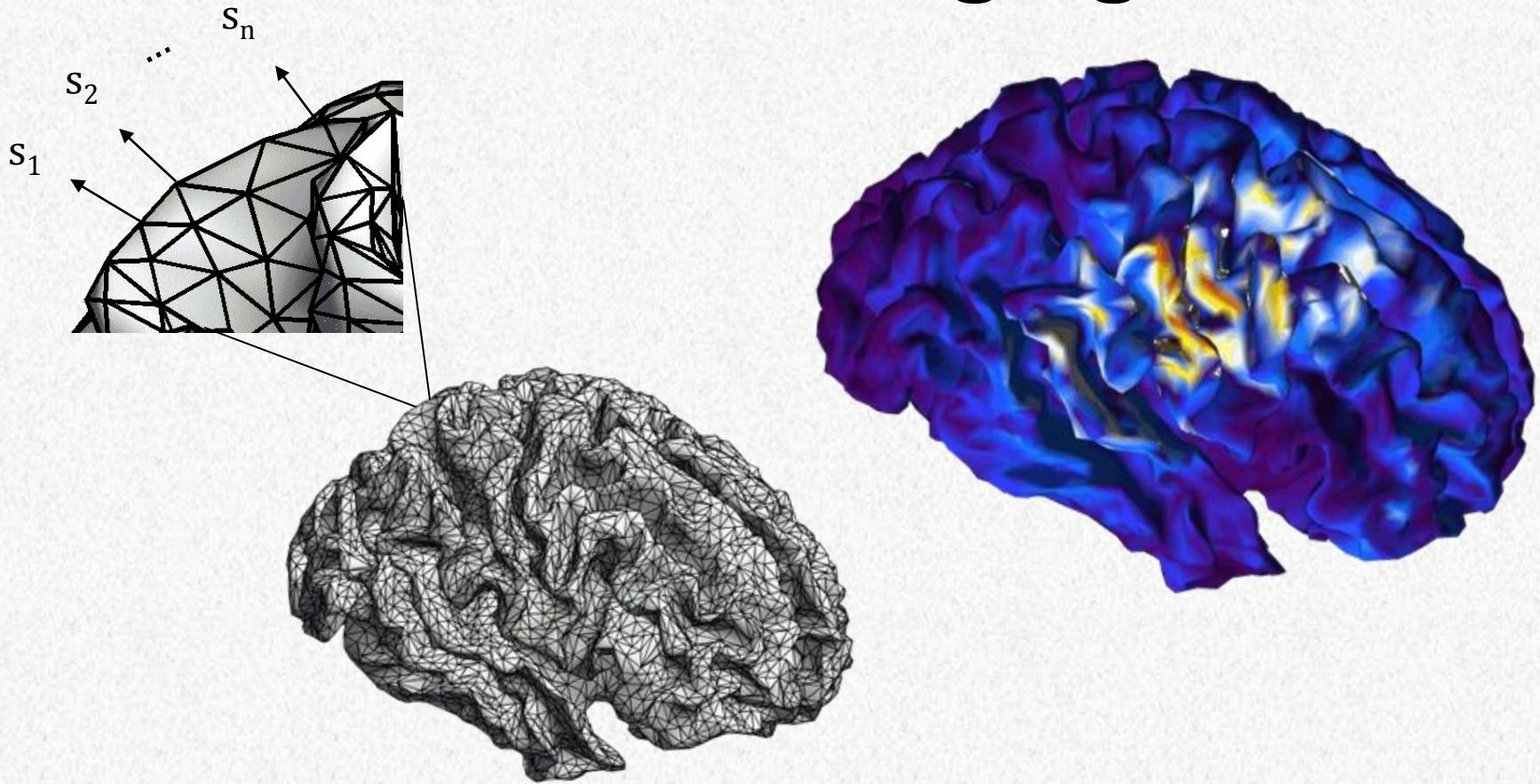
Or in matrix form:

$$m = \begin{matrix} \begin{array}{ccccccc|cc} \hat{e} & m_1 & \hat{u} & \hat{e} & g_1^a & g_1^b & \cdots & \hat{u} \hat{e} & 1 & \hat{u} \\ \hat{e} & m_2 & \hat{u} & \hat{e} & g_2^a & g_2^b & \cdots & \hat{u} \hat{e} & 0 & \hat{u} \\ \hat{e} & \vdots & \hat{u} & \hat{e} & \vdots & \vdots & \ddots & \hat{u} \hat{e} & \vdots & \hat{u} \end{array} \end{matrix} = G \begin{matrix} \begin{array}{c} \hat{e} \\ \hat{e} \\ \vdots \end{array} \end{matrix}$$

$$m = \begin{matrix} \begin{array}{ccccccc|cc} \hat{e} & m_1 & \hat{u} & \hat{e} & g_1^a & g_1^b & \cdots & \hat{u} \hat{e} & q^a & \hat{u} \\ \hat{e} & m_2 & \hat{u} & \hat{e} & g_2^a & g_2^b & \cdots & \hat{u} \hat{e} & q^b & \hat{u} \\ \hat{e} & \vdots & \hat{u} & \hat{e} & \vdots & \vdots & \ddots & \hat{u} \hat{e} & \vdots & \hat{u} \\ \hat{e} & \vdots & \hat{u} & \hat{e} & \vdots & \vdots & \vdots & \hat{u} \hat{e} & \vdots & \hat{u} \end{array} \end{matrix} = G \begin{matrix} \begin{array}{c} \hat{e} \\ \hat{e} \\ \vdots \end{array} \end{matrix} + \begin{matrix} \begin{array}{c} n_1 \\ n_2 \\ \vdots \\ n \end{array} \end{matrix}$$

Sensor (measurement) noise

# inverse imaging

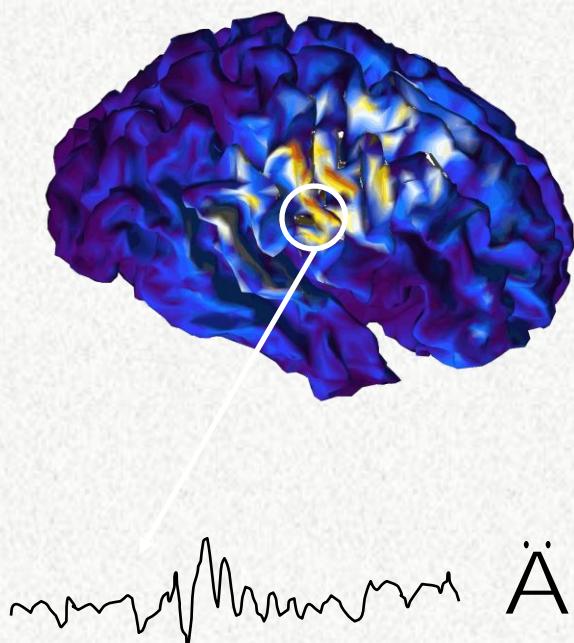


Assume a density of dipoles oriented normally to the cortical surface. Find their amplitude.

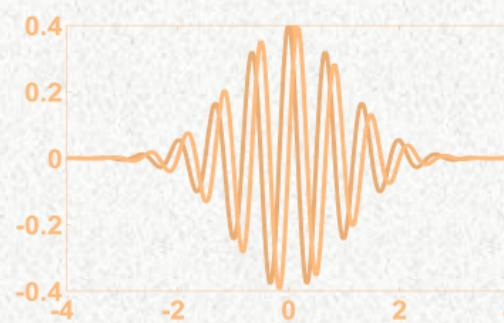
Minimum-norm estimation (MNE):  $m = Gq + n \vdash \hat{q} = \arg \min_q \|m - Gq\|^2$   
(Hauk2004, NeuroImage)

Minimum-variance beamforming (LCMV):  $\hat{q} = Hm \Leftarrow \hat{q}^a = H_a^T m \Leftarrow H_a = \arg \min_h h^T \left( \text{Cov}(m) \right) h$   
(Hui2010, NeuroImage)

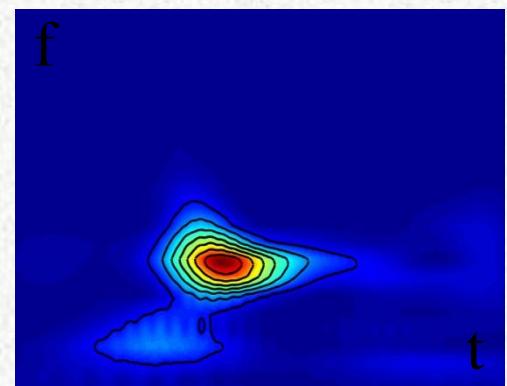
# time-frequency decompositions



θ band: 4-7Hz  
α band: 8-14Hz  
β band: 15-30Hz  
γ band: 30-100Hz



=



$X^{st}$

$$w^{tf} = \frac{1}{(\sigma_{tc} \sqrt{\pi})^{1/2}} e^{-\frac{t^2}{2\sigma_{tc}^2}} e^{i2\pi f_c t}$$

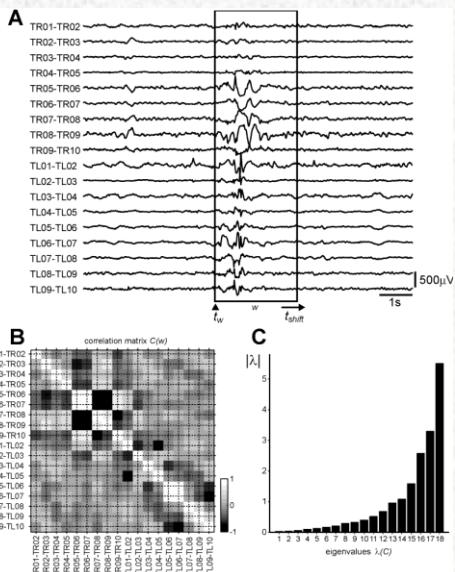
$$C^{stf} = X^{st} * w^{tf}$$

s: spatial index  
t: temporal index  
f: frequency index

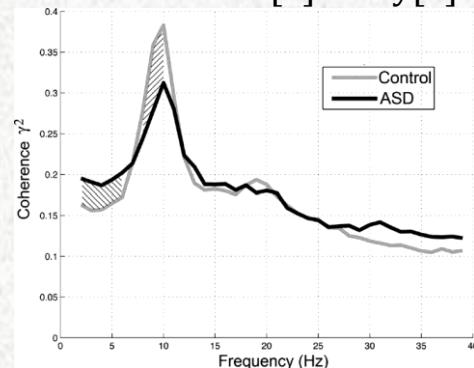
# connectivity & EEG/MEG

- Connectivity = Relation between  $x[n]$  and  $y[n]$

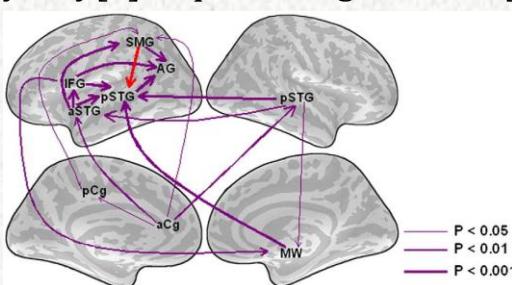
Correlation: do  $x[n]$  and  $y[n]$  change at the same time?



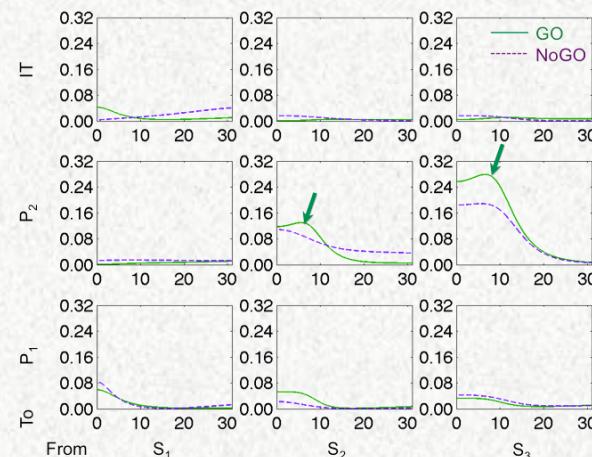
Coherence: do  $x[n]$  and  $y[n]$  change at the same time for frequency  $f$ ?



Causality: Is  $y[n]$  required to generate  $x[n]$ ?



Granger causality: Does  $y[n-1]$  help predict  $x[n]$ ?



→ All methods benefit from the high temporal resolution of EEG/MEG.

# BrainStorm demonstration

