MRC Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

EEG/MEG 1:

History, Measurement, Signal Generation

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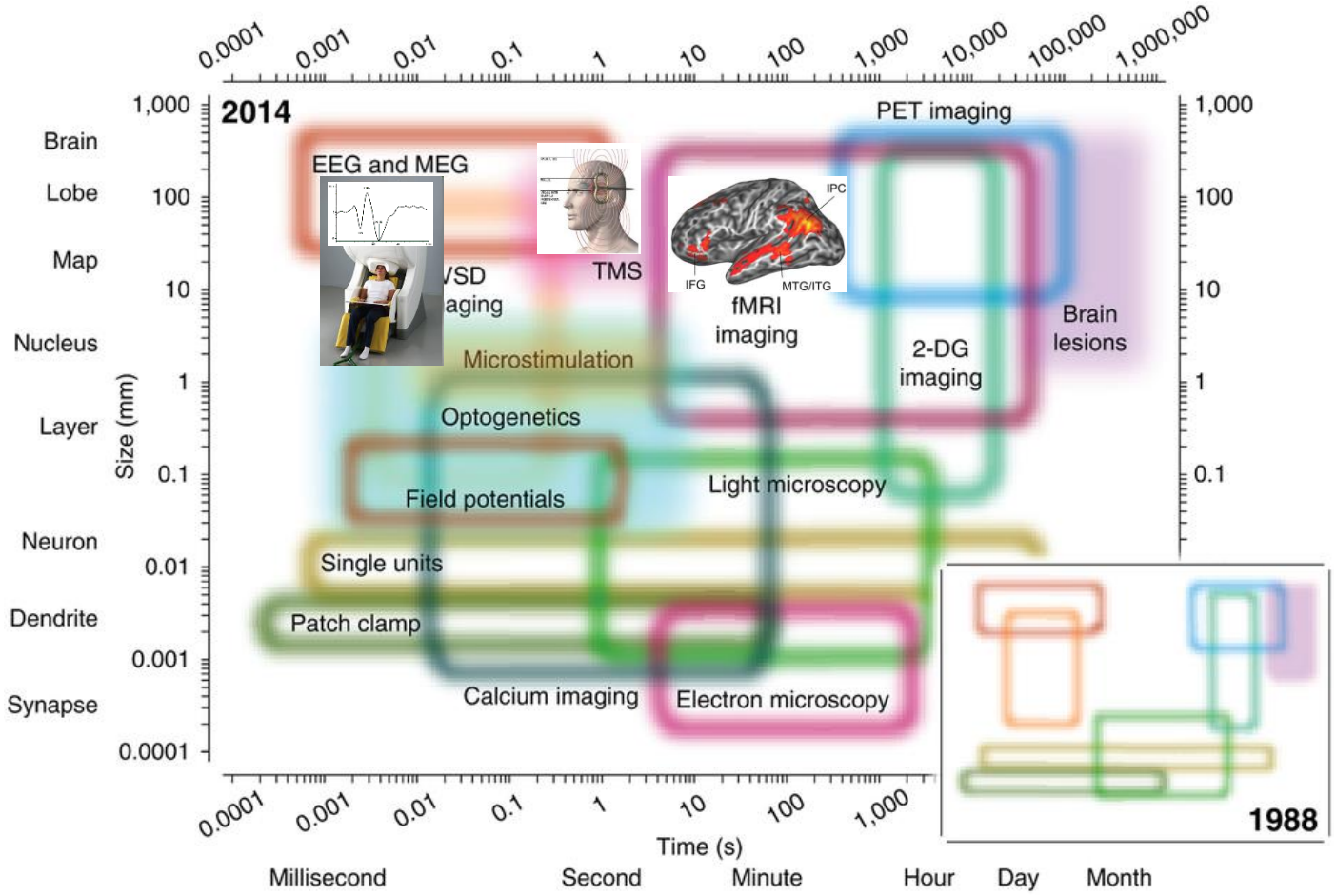
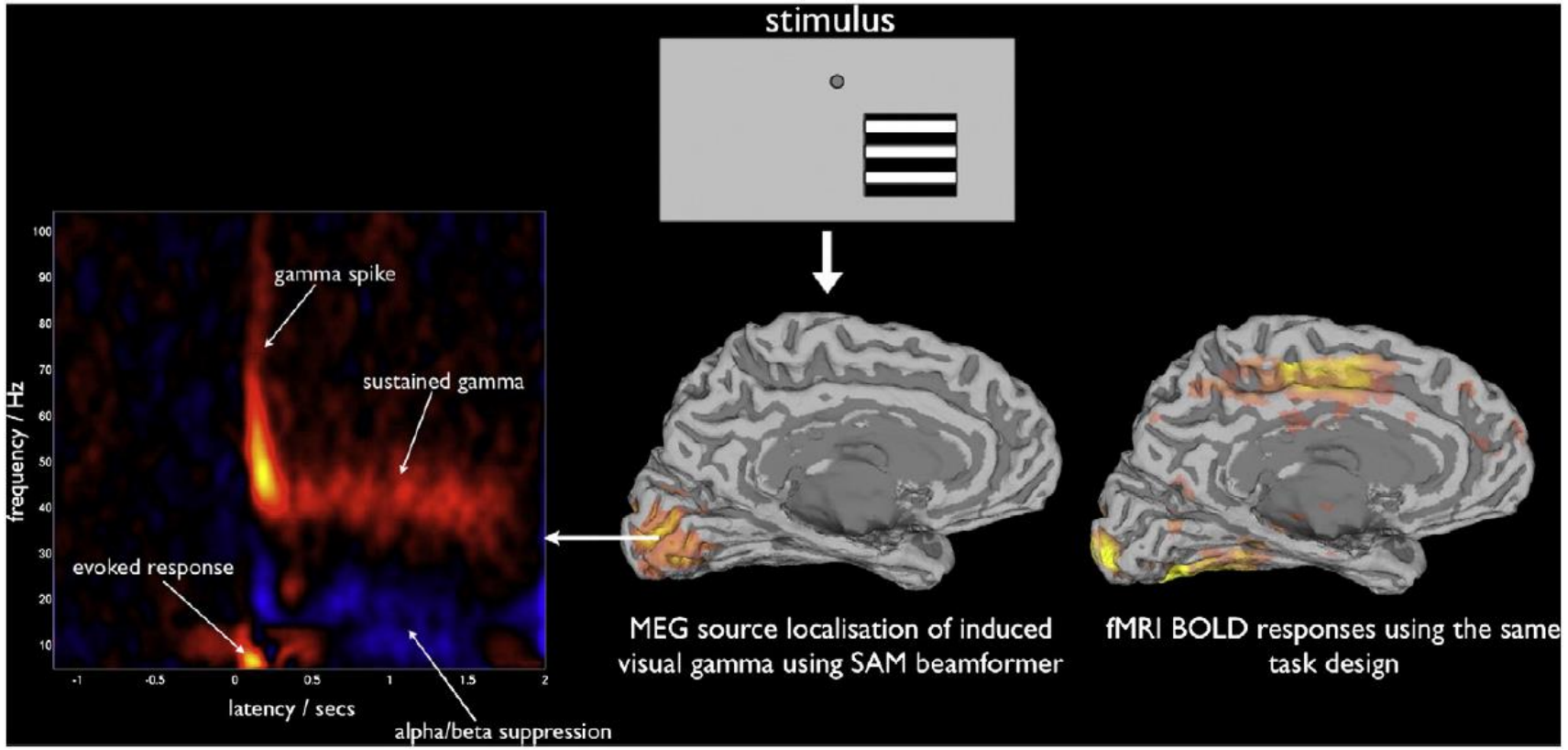
Neuroimaging Methods Vary With Respect To Spatial and Temporal Resolution

(and their invasiveness, physiology, etc.)



Seijnowki, Churchland, Movshon, Nat Nsc 2014

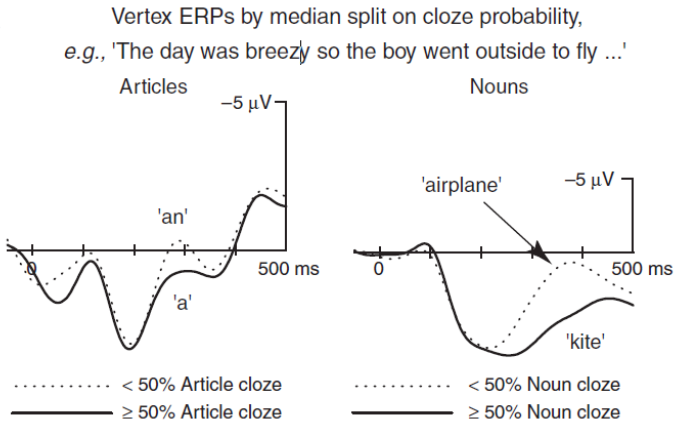
Which “Neural Activity” Do You Mean?



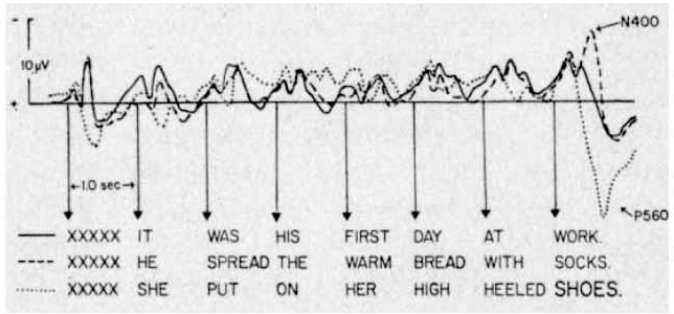
Singh, NI 2012

EEG/MEG "Activity" Can Be Analysed In A Number Of Ways, e.g.

Event-Related Potentials

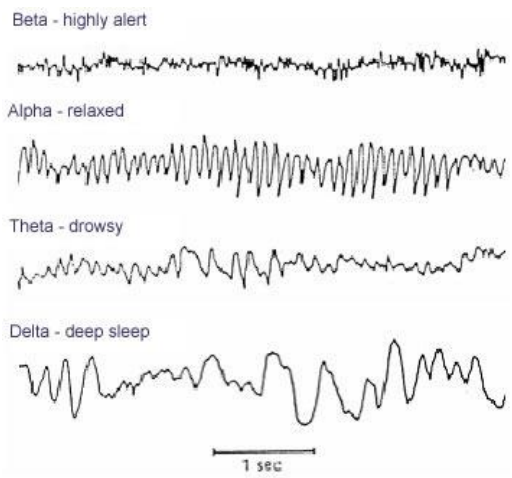


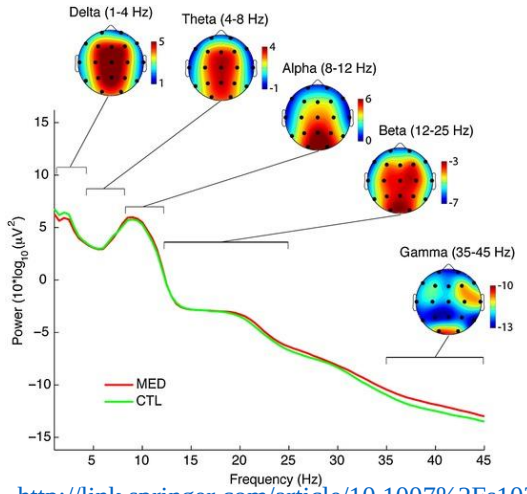
deLong, Urbach, Kutas, Nat Nsc 2005



Kutas&Hillyard, Science 1980

Brain "Rhythms"/"Oscillations"

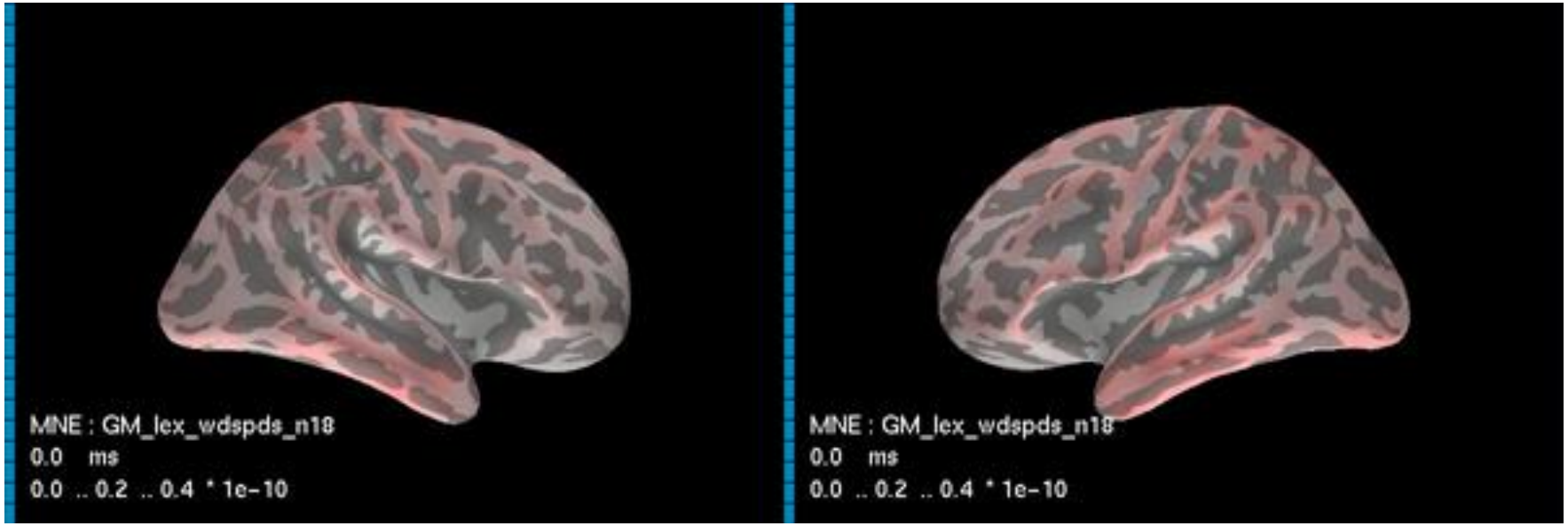




http://link.springer.com/article/10.1007%2Fs10339-009-0352-1/

What We Really Want:
Spatio-Temporal Brain Activity

(Movies rather than pictures)



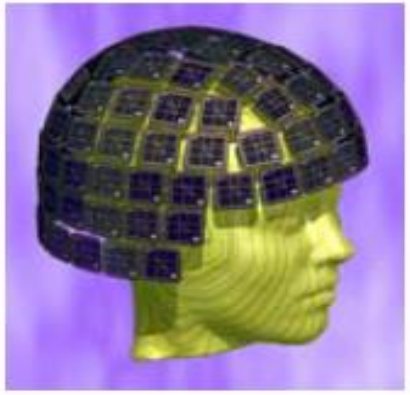
The Fast Evolution of MEG

1983
by HUT
4 channels
30 mm in diameter
(coverage: 7 cm^2)
Axial

1986
by HUT
7 channels
93 mm in diameter
(coverage: 68 cm^2)
Axial

1989
by HUT
24 channels
125 mm in diameter
(coverage: 123 cm^2)
Planar

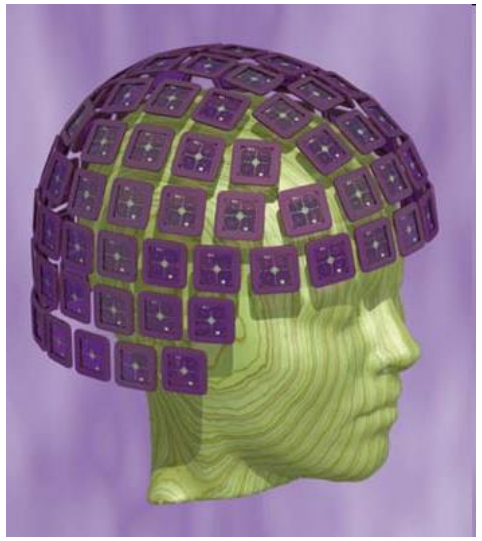
1991
by Neuromag
122 channels
whole head
(coverage: 1100 cm^2)
Planar
12 Deliveries



1997
by Neuromag
306 channels
whole head
(coverage: 1220 cm^2)
Planar & Magnetometers

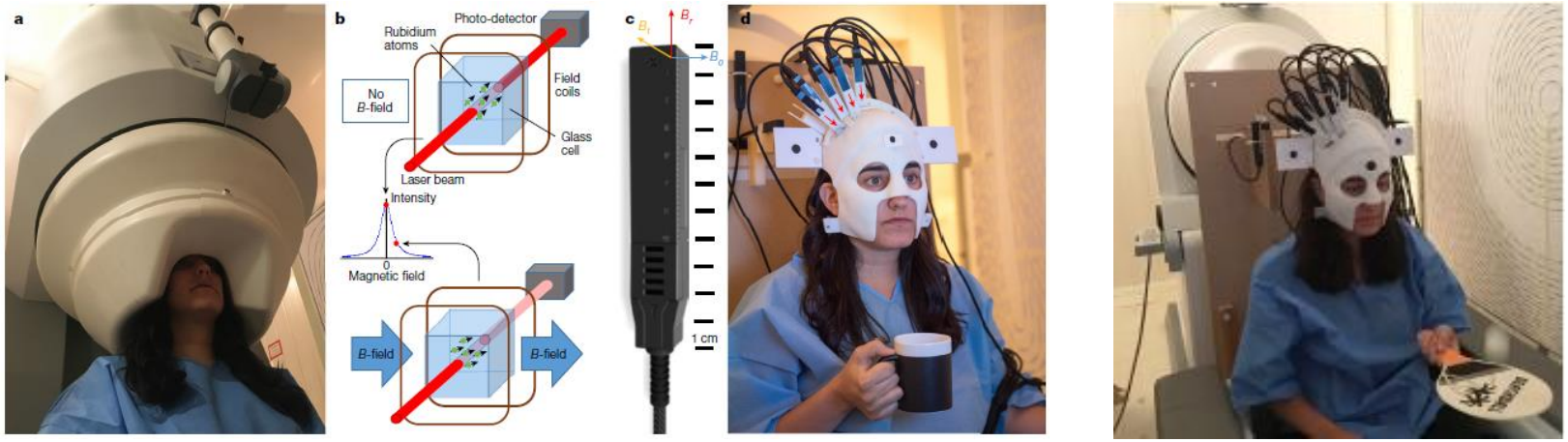
MEG – The Present

e.g. MEGIN Triux System
306 MEG sensors (102 magnetometers, 204 gradiometers)
64 EEG electrodes

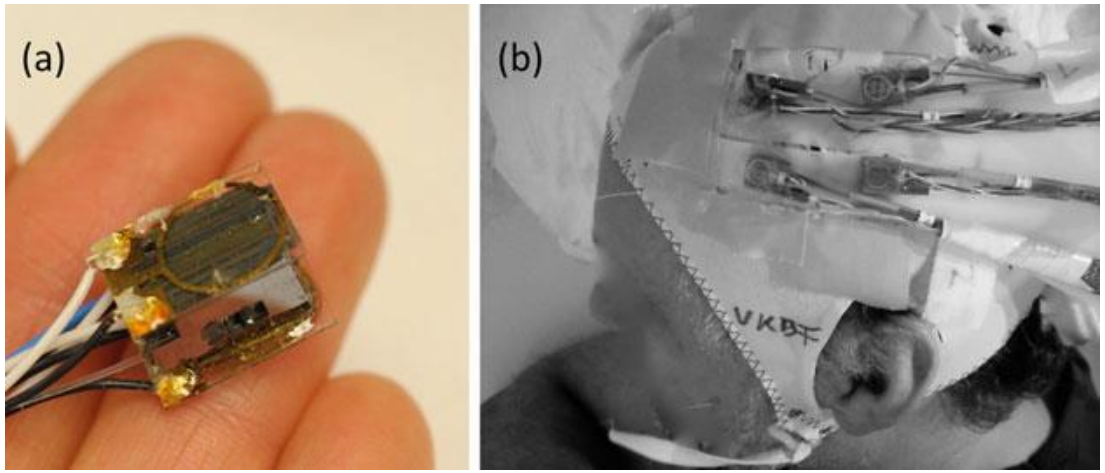


MEG – The (Near) Future

On-Scalp Optically Pumped Magnetometers



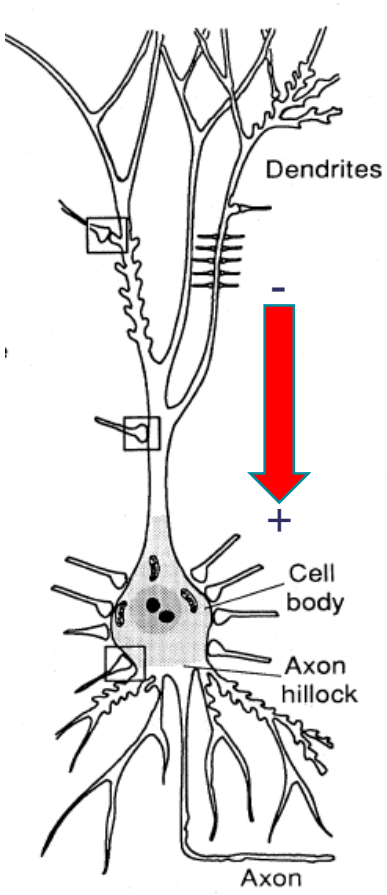
https://twitter.com/wellcometrust/status/976534659436703744 Boto et al., Nature 2018



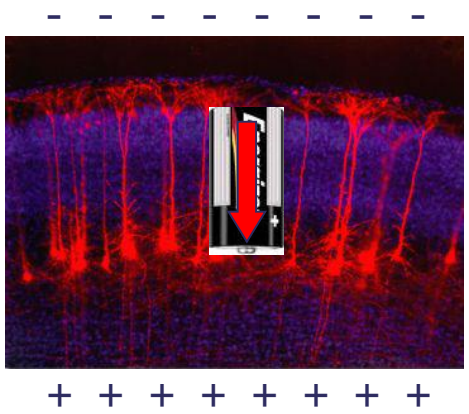
Knappe, Sander, Trahms, chapter in “Magnetoencephalography” by Supek & Aine (edts)

The Measurement Of EEG/MEG Signals

Main Generators of EEG/MEG Signals



- **Apical dendrites of pyramidal cells**
- **NOT action potentials** (too short-lived and quadrupolar)
- **EEG/MEG: same generators, different sensitivity**

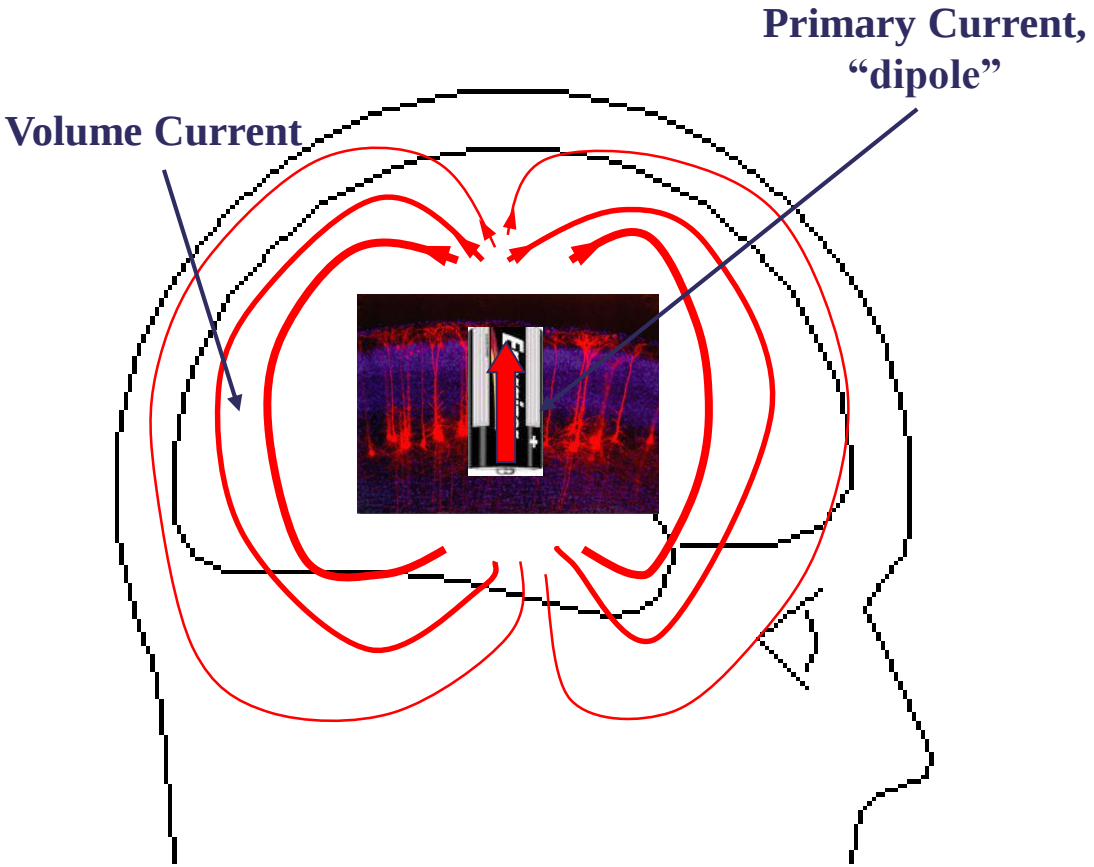


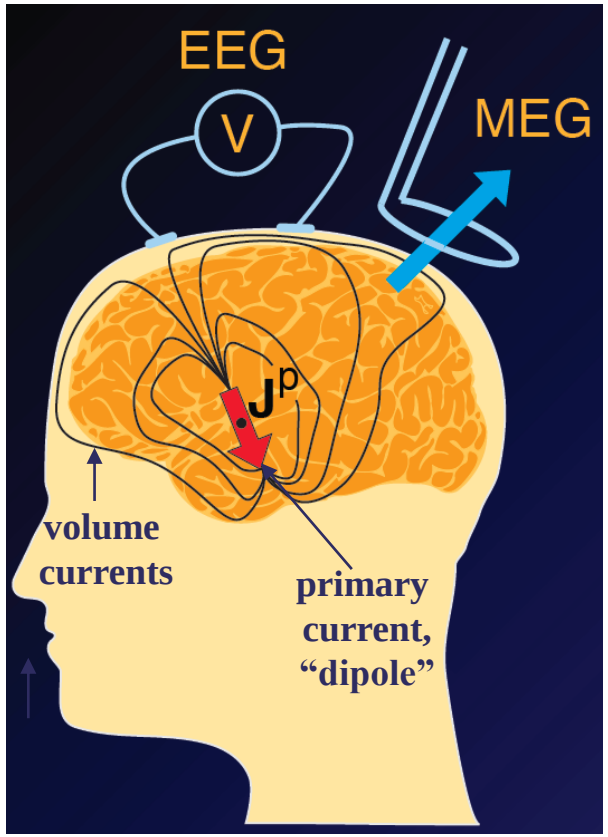
Dipolar currents

- ~ 1 Million synapses needed to activate simultaneously
- Luckily: ~10000 cells per mm^2, ~ 1000 synapses per cell

  => several mm^2 can produce measurable signal

Primary and Volume Currents





http://www.nmr.mgh.harvard.edu/meg/pdfs/talks/

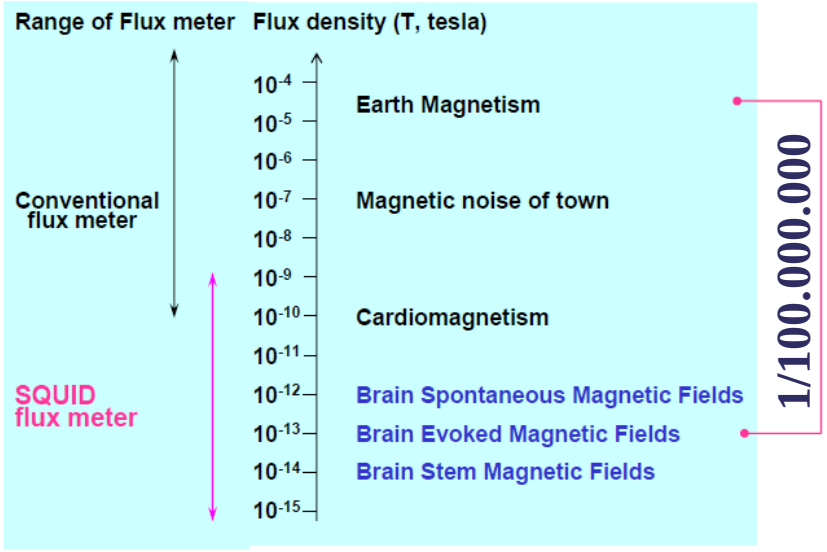
All effects are instantaneous.

Volume currents affect both EEG and MEG –

but EEG more than MEG

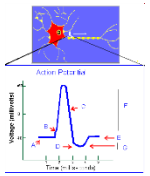
Scales of Electric and Magnetic Signals

Magnetoencephalography (MEG)



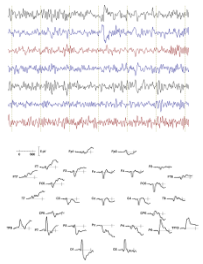
Electroencephalography (EEG)

Household Batteries
~ 1-12 V



Cell Membrane Potentials
~ 70 mV

ECG:
~ 1mV

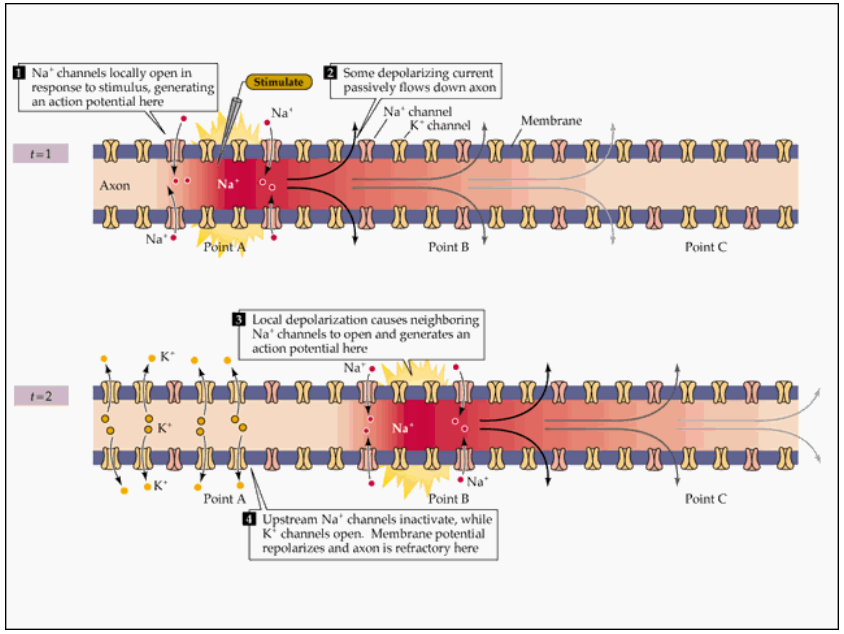


Raw EEG: ~ 30 µV
Eye blinks: > 100 µV

ERPs: ~ 0-10 µV

EEG/MEG Are Mostly Insensitive To Action Potentials

Action potentials are caused by active cellular mechanisms,
not passive “Ohmic” currents.
(Very different speeds)



http://www.arts.uwaterloo.ca/~bfleming/psych261/lec4se21.htm

Action potentials are quadupolar

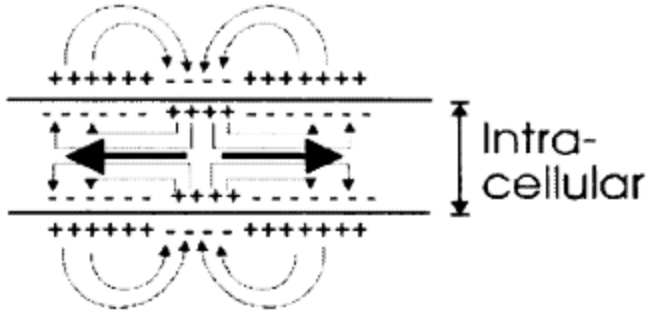


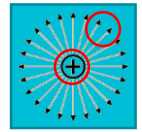
Figure I.1: *Schematic representation of an action potential*
Wieringa thesis, http://www.medcat.nl/megeeg/chap1.htm

Currents due to action potentials are very short-lived and asynchronous as well as “quadrupolar” (i.e. two opposing dipoles).

The Physics of EEG/MEG:
Quasi-Static Approximations of Maxwell's Equations

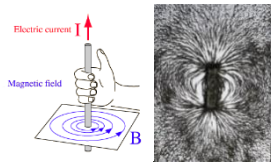
- The summed electric flux around a close surface is proportional to the total electric charge enclosed within this surface (Gauss's Law)

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0} = 0 \; (for \; dipoles)$$



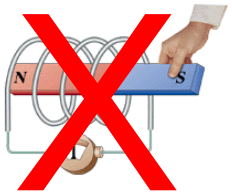
- *Magnetic field lines are closed (Gauss's Law for magnetism)*

$$\nabla \cdot \boldsymbol{B} = 0$$



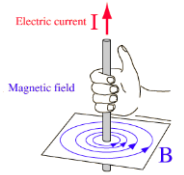
- *We do not consider any inductive effects (Faraday's Law):*

$$\nabla \times \boldsymbol{E} = 0$$



- *Magnetic fields are only caused by static currents (Ampere's Law):*

$$\nabla \times \boldsymbol{B} = \mu_0 \mathbf{J}$$

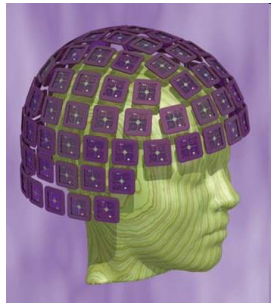


The relationship between EEG/MEG measurements and their brain sources is instantaneous (no "waves").

Different Sensors and their Sensitivities (Leadfields)

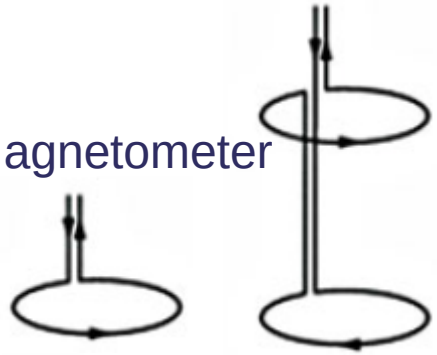
Leadfields are "sensitivity profiles" of individual sensors.

Each sensor is maximally sensitive to sources oriented along the arrows, and insensitive to sources perpendicular to the arrows.



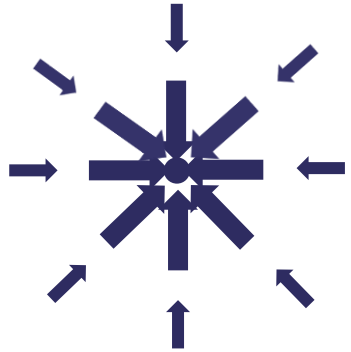
Axial Gradiometer

Magnetometer

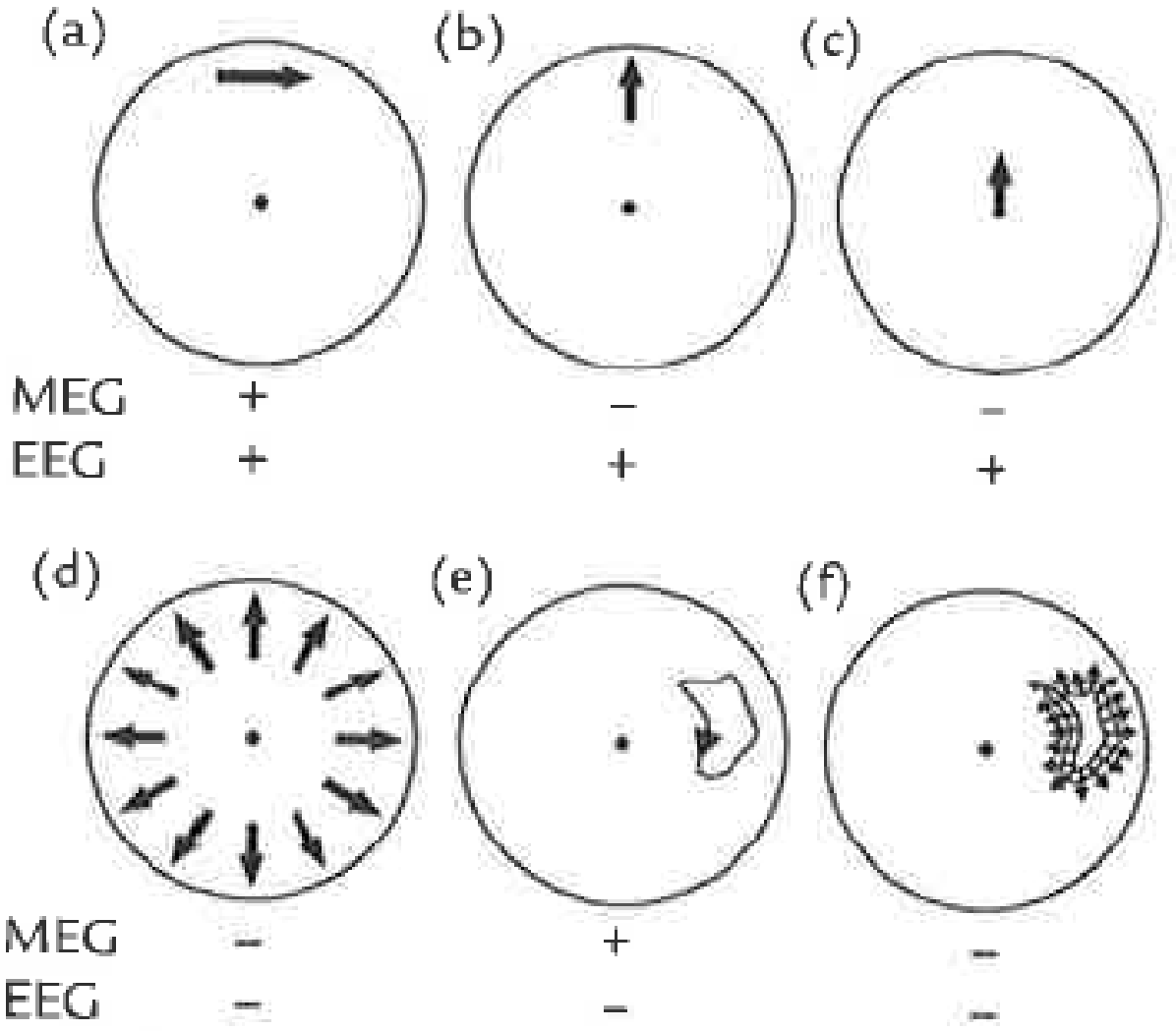


Planar Gradiometer(s)

EEG Electrode



EEG and MEG Are Differentially Sensitive To Radial and Tangential Sources



MEG is relatively insensitive to radial currents, and therefore also to deep currents.

Some complex source distributions may not produce EEG or MEG signals.

MEG-EEG Primer, Hari & Puce, OUP 2017

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Thank you