Electroencephalography
EEG

Invented in 1924

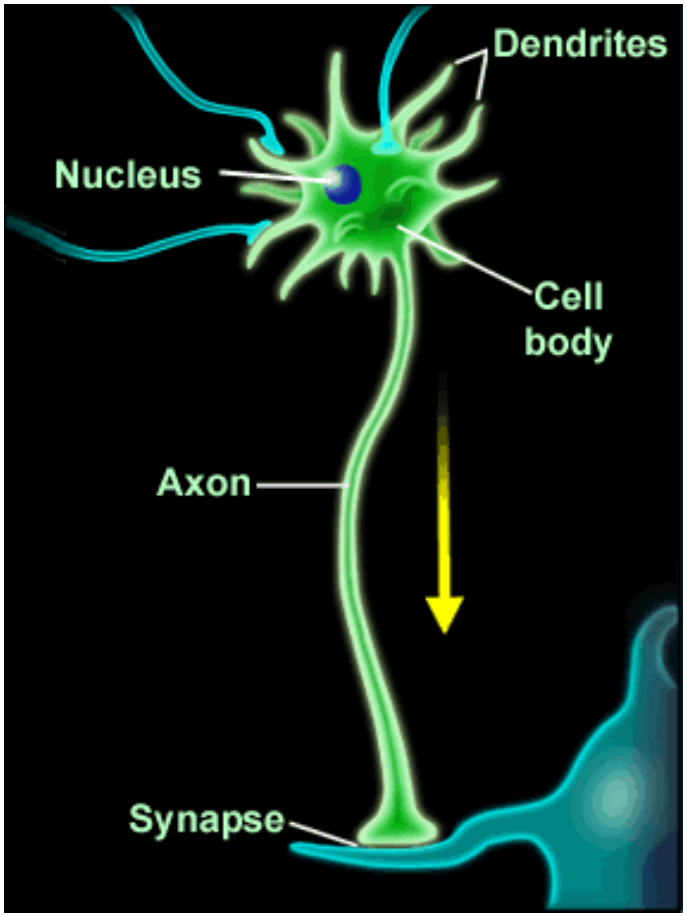
Magnetoencephalography
MEG

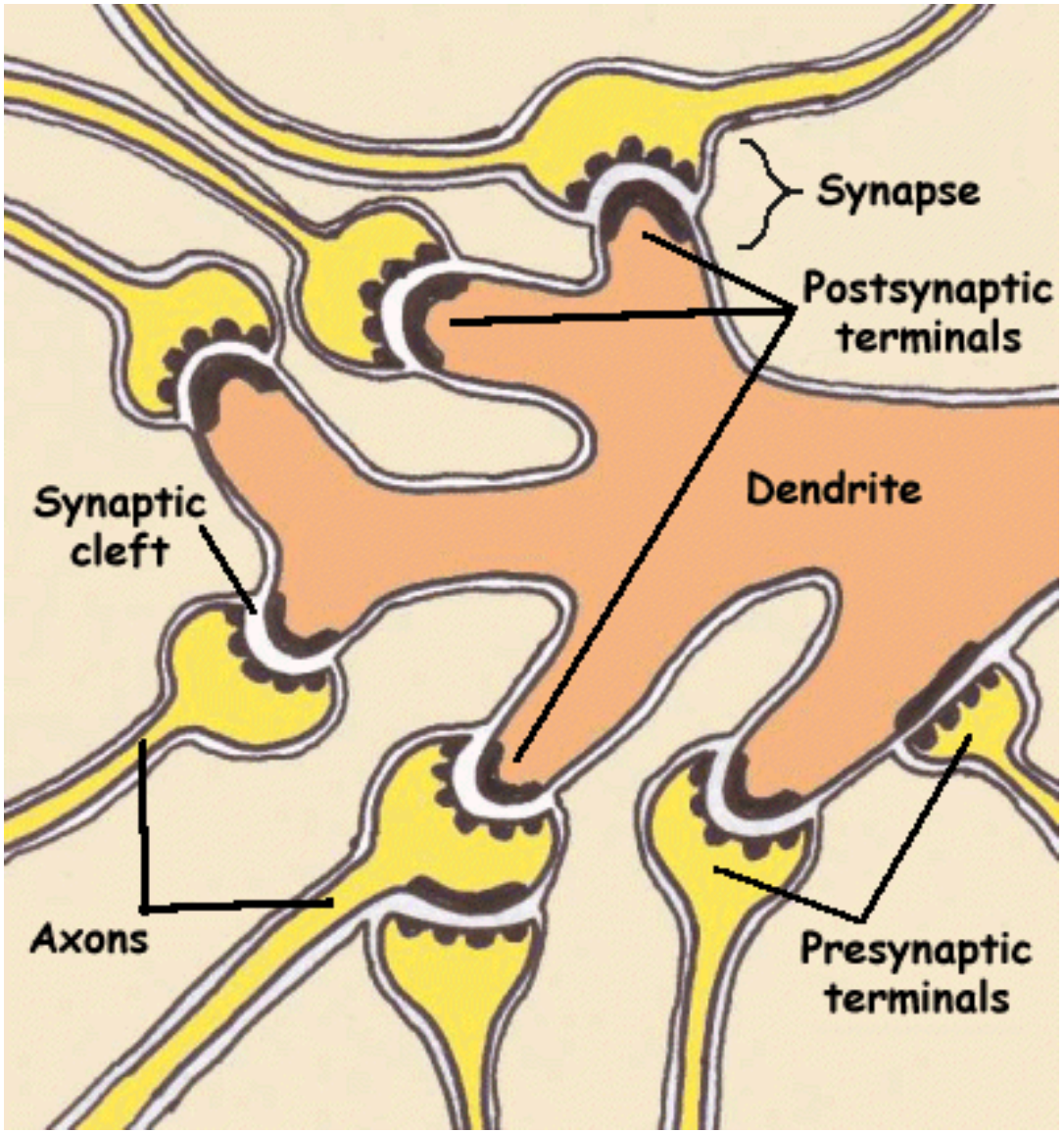
Invented in 1972

Electromagnetic techniques

- Millisecond temporal resolution
- Neurons communicate with each other thousands of times per second by sending each other tiny electrical impulses
- Populations of neurons are connected into networks
- When networks fire ***in synchrony***, the dynamics of the electric activity can be detected and recorded outside the skull

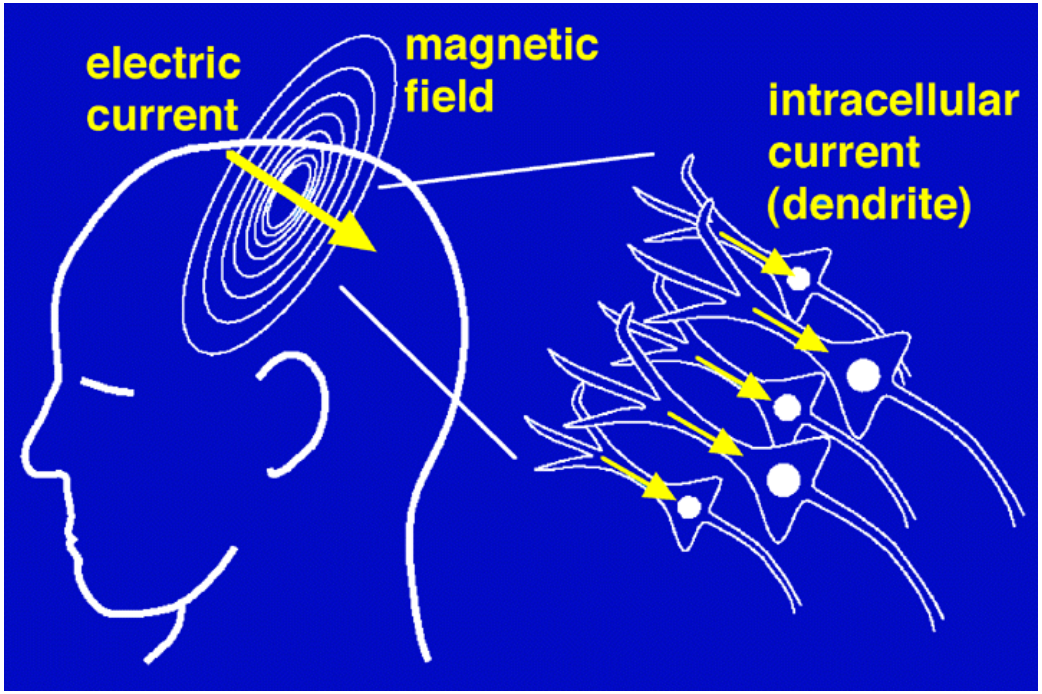
Main source of the signal: Post-synaptic current flow along the dendrites of (pyramidal) nerve cells

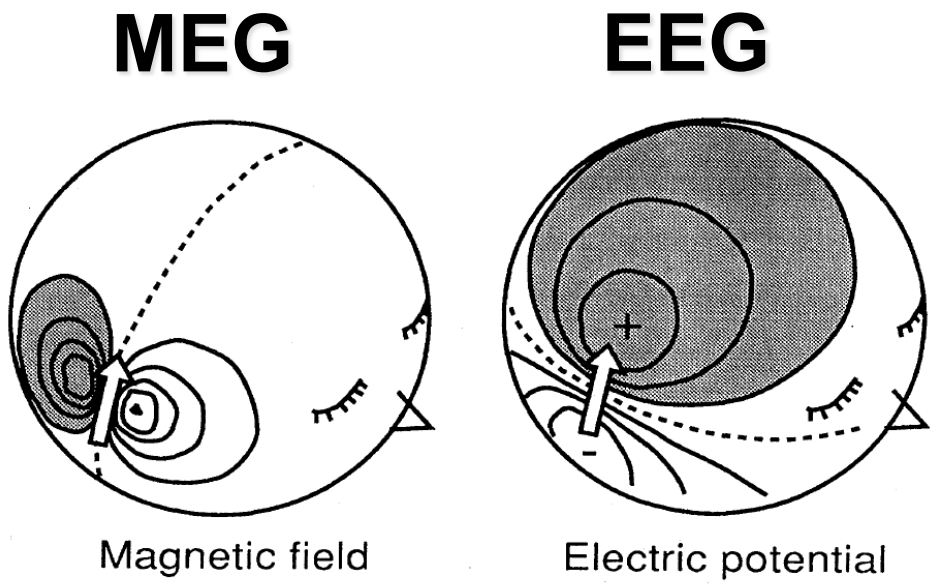




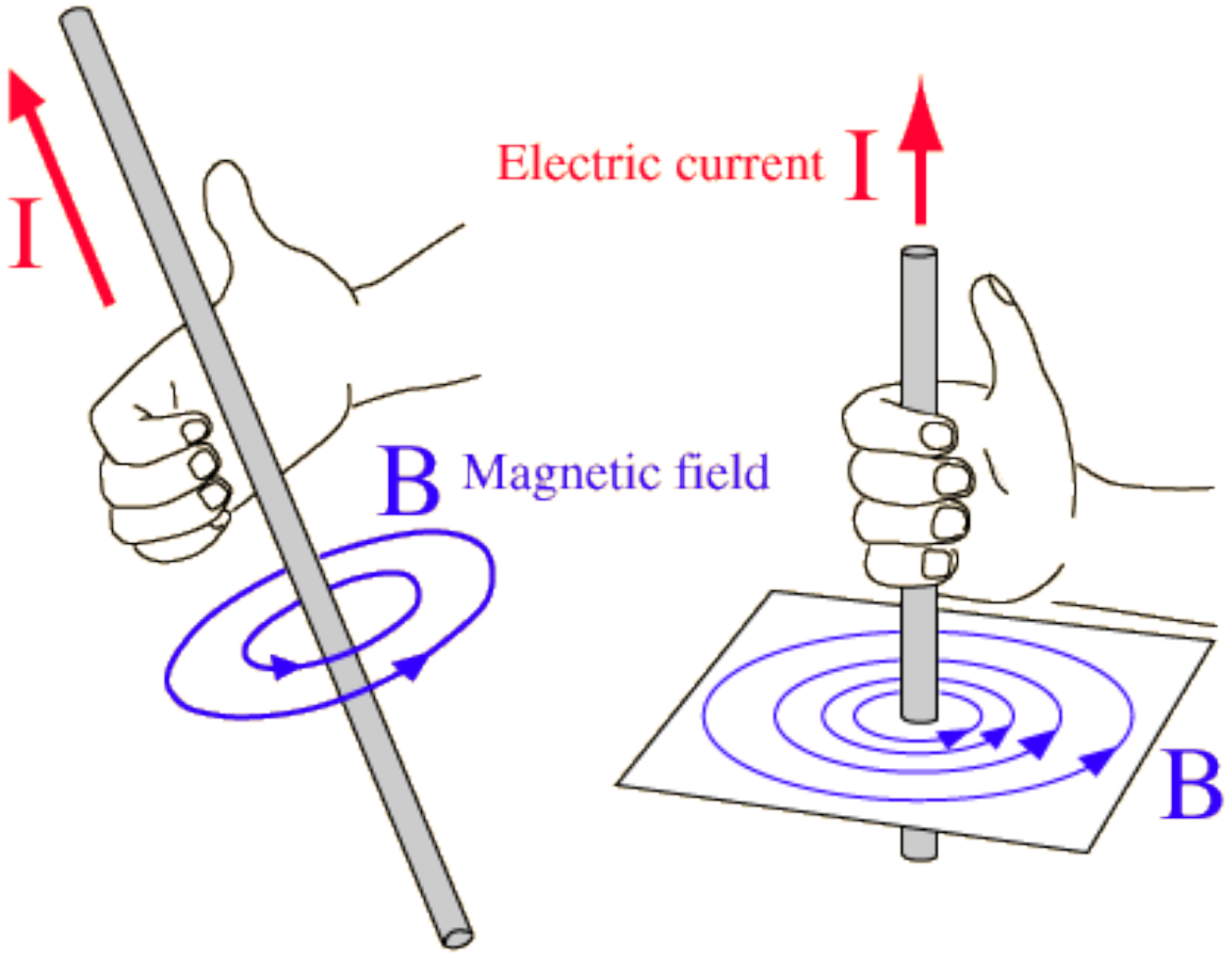
An electric current creates an electric potential and a magnetic field

- EEG (electroencephalography): electric potentials
- MEG (magnetoencephalography): magnetic fields



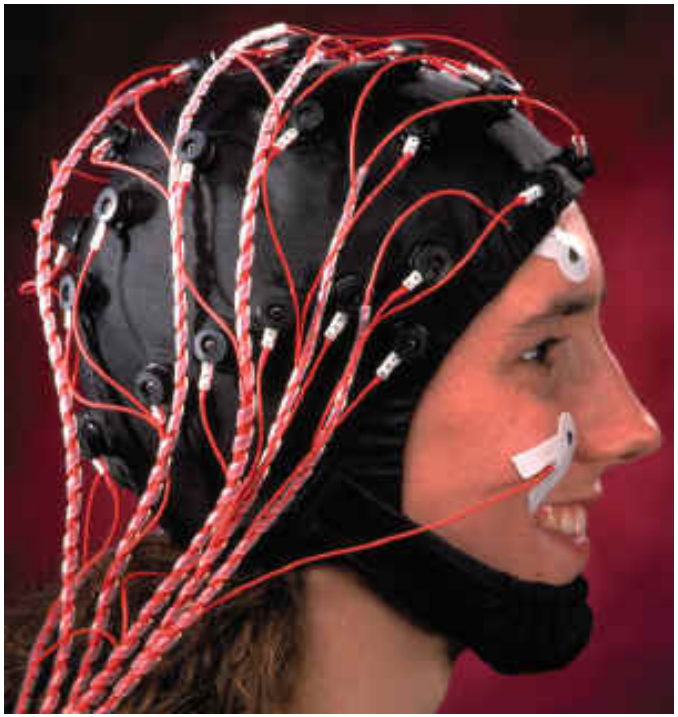


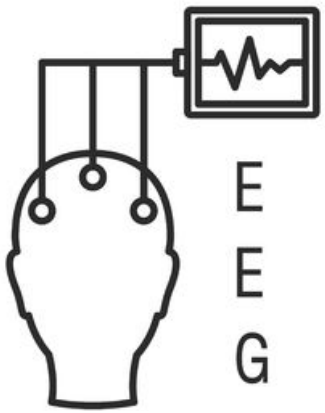
The right-hand rule: When the thumb of the right hand is pointing in the direction of the current, the fingers of the right hand curl in the direction of the magnetic field



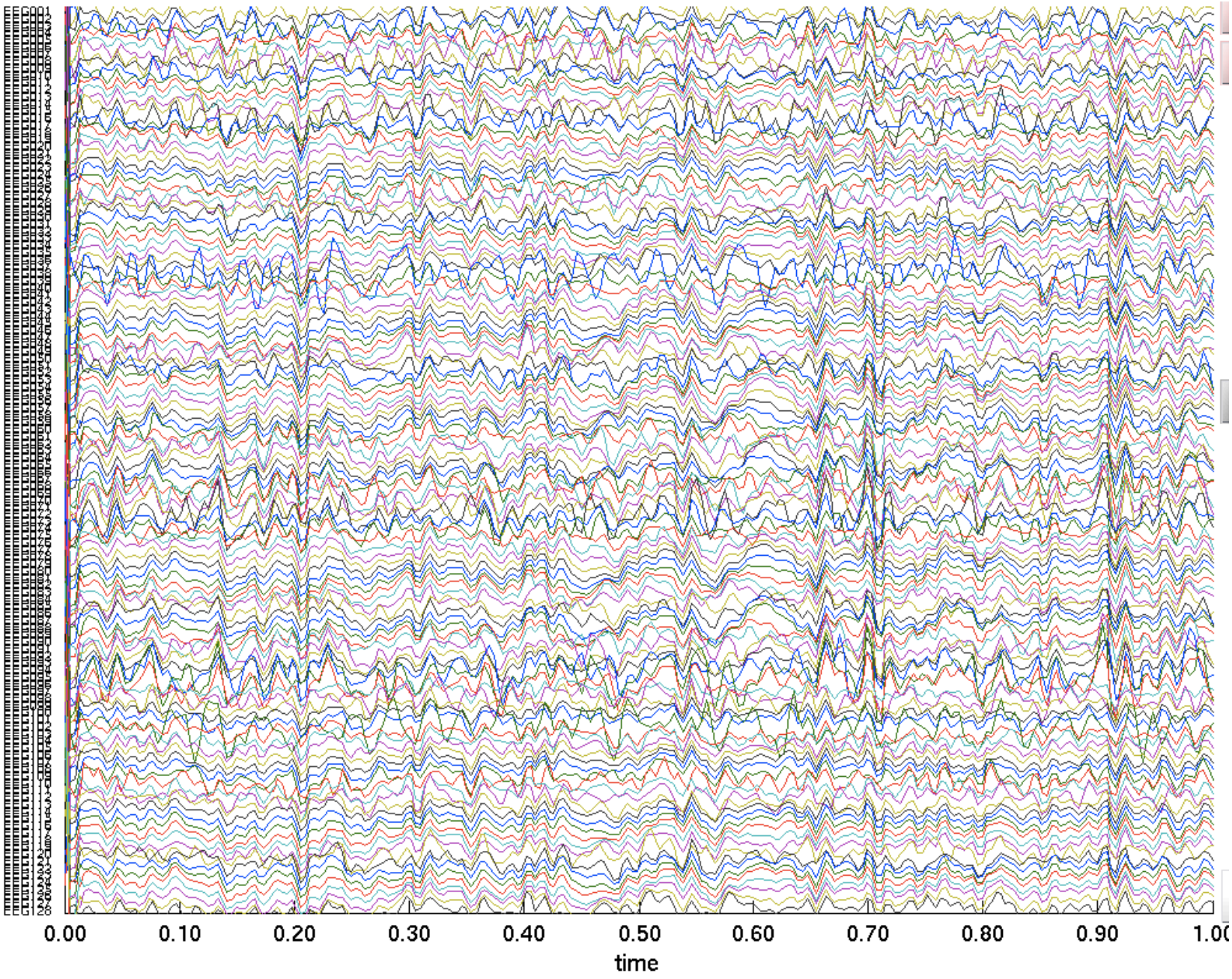
MEG

EEG



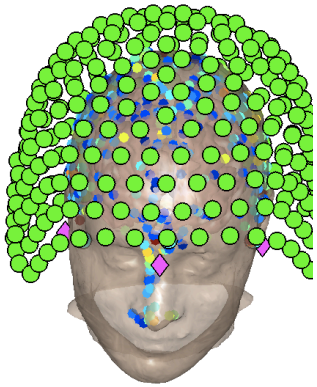


Each line shows the recording from one EEG electrode.

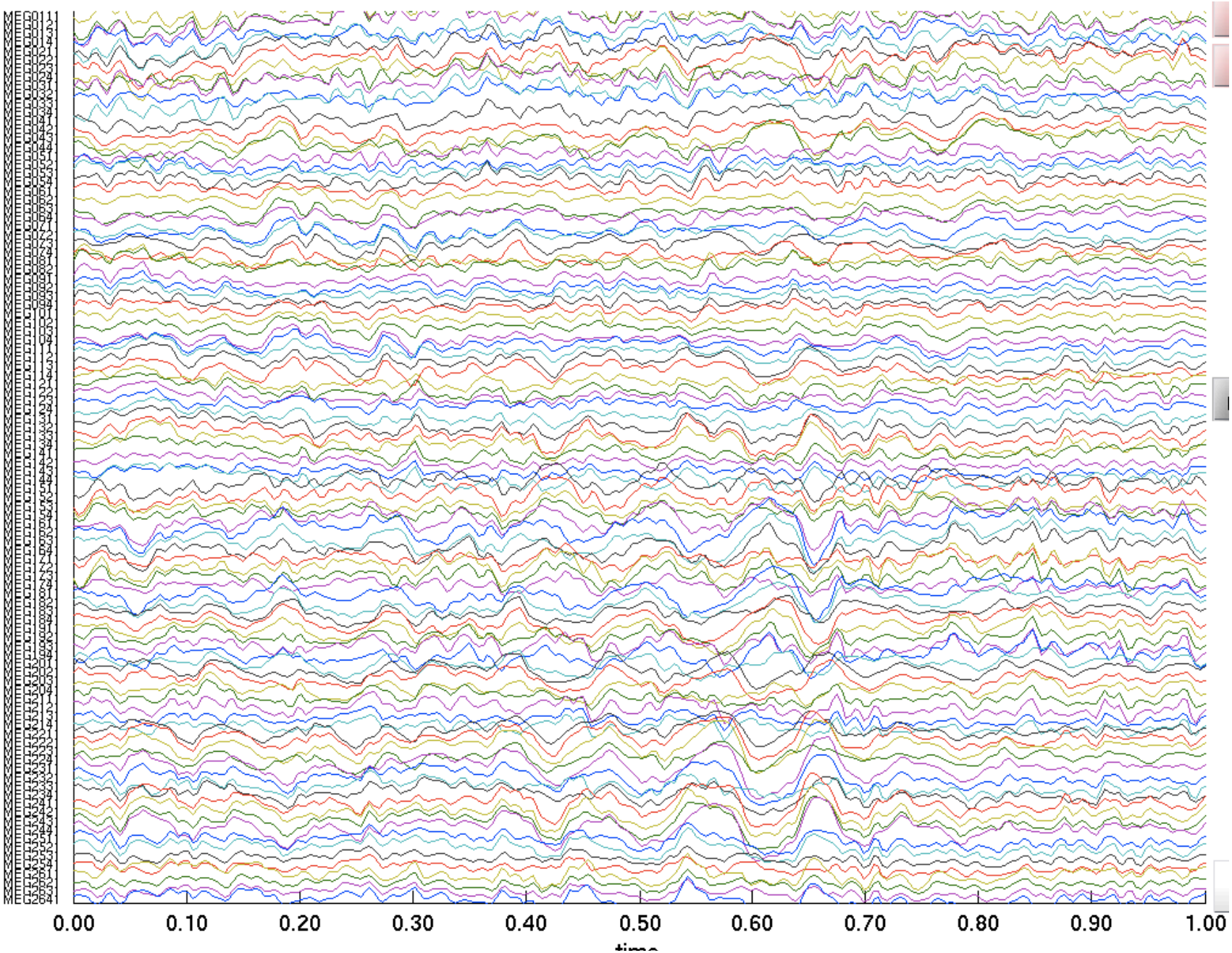


Raw EEG data

http://www.fieldtriptoolbox.org/workshop/natmeg/preprocessing/



Each line shows the recording from one MEG sensor.



Raw MEG data

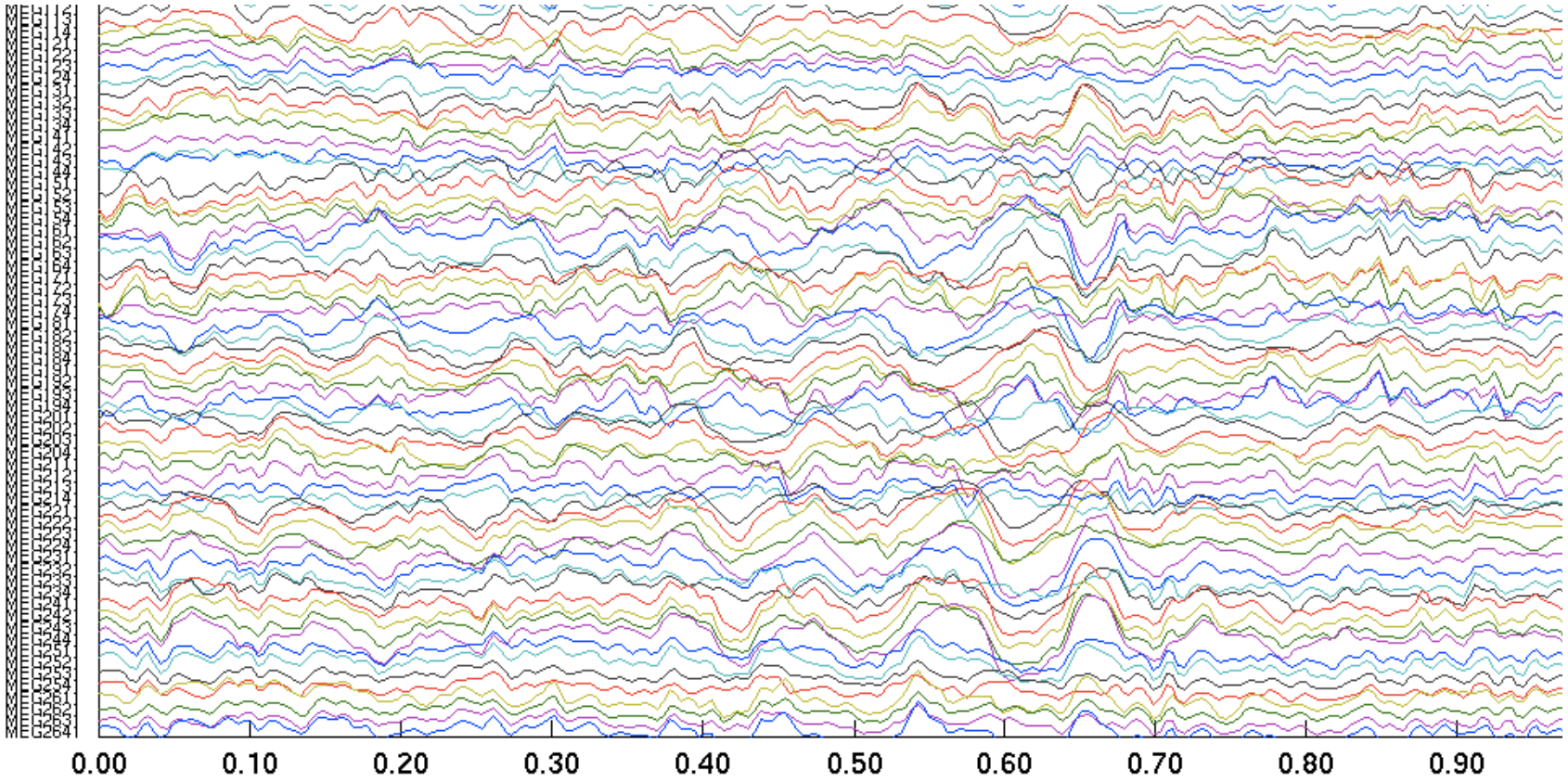
http://www.fieldtriptoolbox.org/workshop/natmeg/preprocessing/

Signal vs. noise

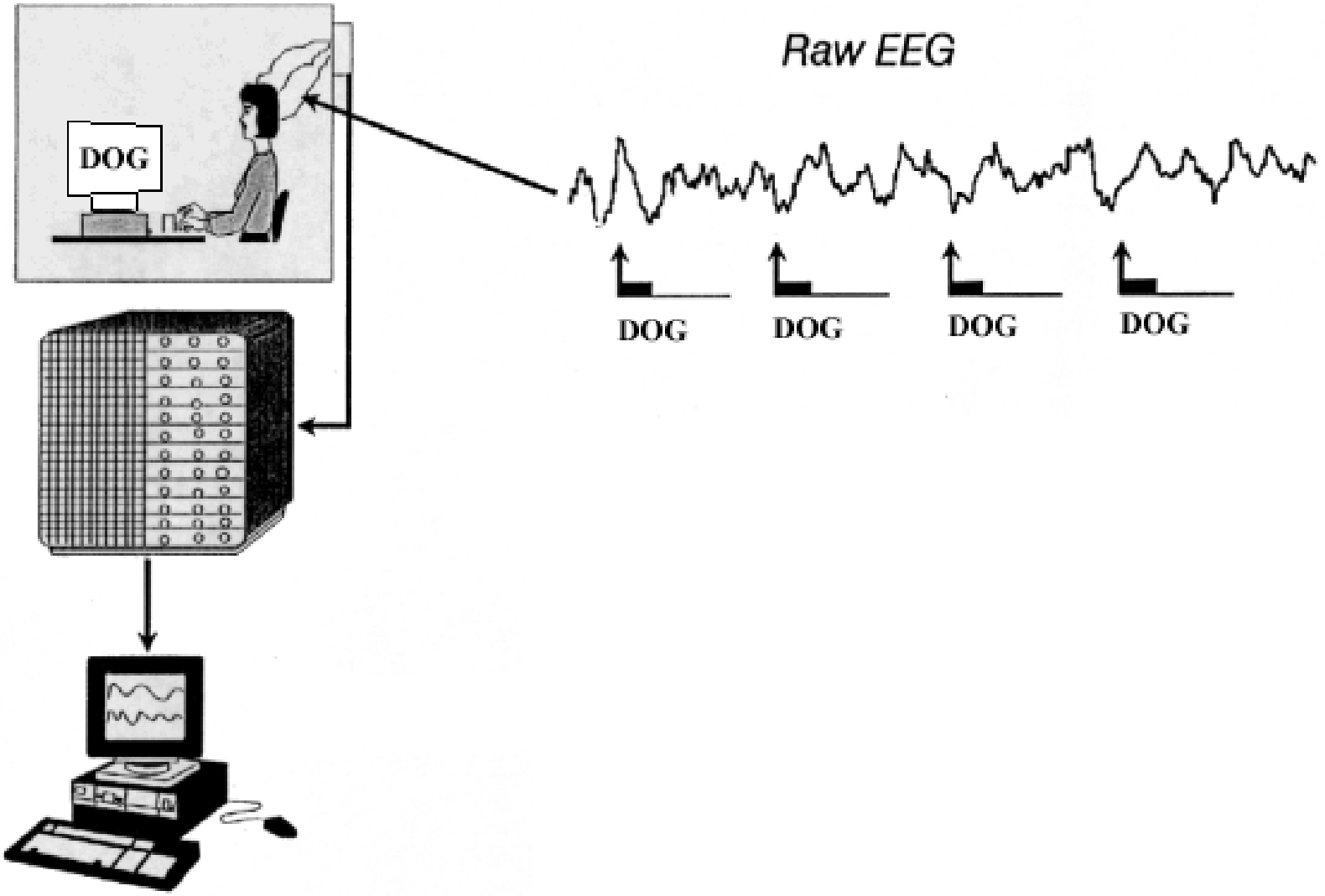
Raw data reflect:

- Brain responses to the experimental stimuli (signal)
- Brain activity reflecting everything else the subject is thinking of (brain noise)
- Shifts in electric fields created by body movements, especially the eyes! (body noise)
- In MEG, shifts in electric fields created in the environment (environmental noise).

How can we separate the signal from the noise?



Averaging: Revealing event-related activity
ERP = Event-related potential (EEG)
ERF = Event-related field (MEG)



http://neurocog.psy.tufts.edu/images/ERP_technique.gif

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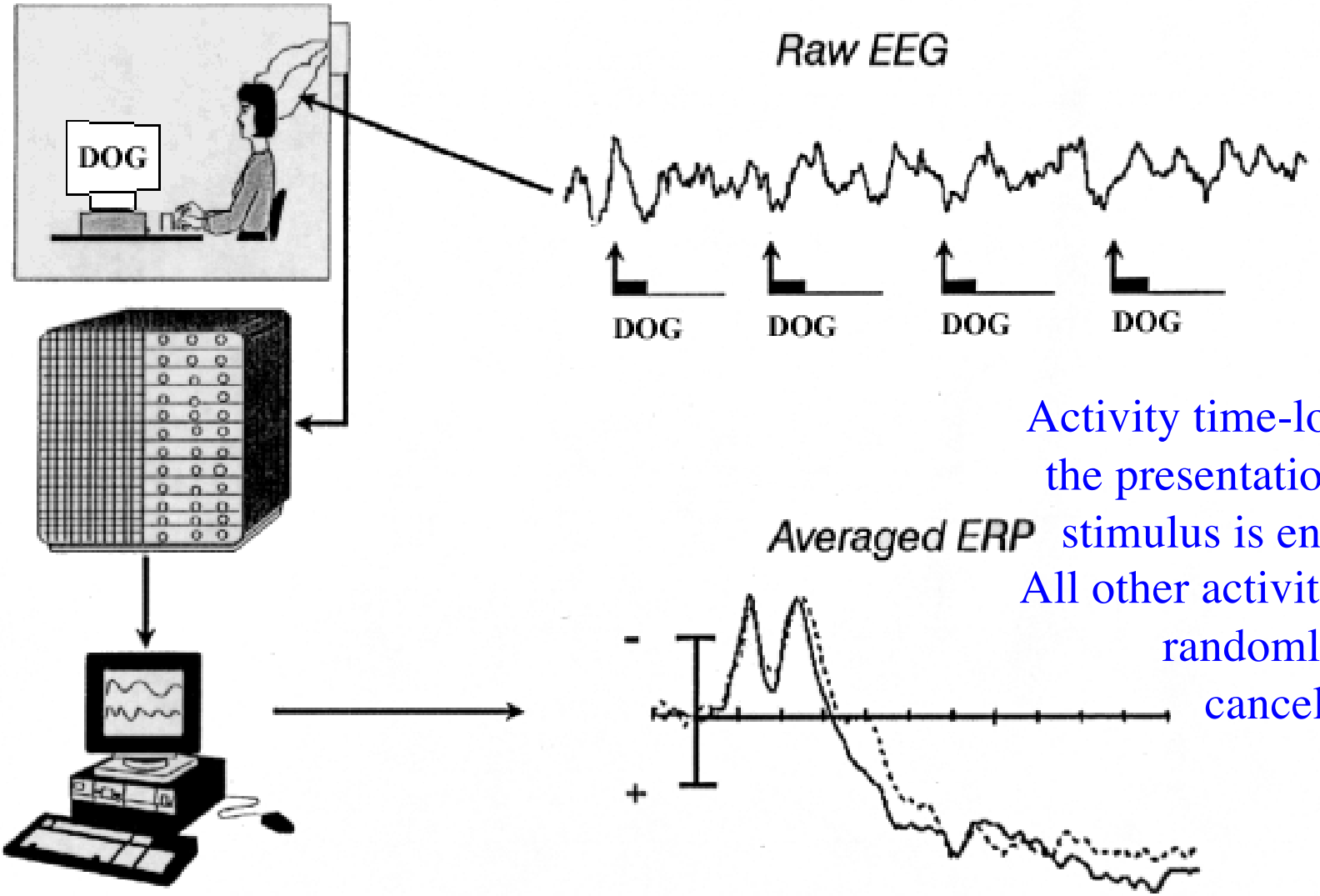

Activity time-locked to the presentation of the stimulus is enhanced. All other activity varies randomly and is cancelled out.

http://neurocog.psy.tufts.edu/images/ERP_technique.gif

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- In MEG, shifts in electric fields created in the environment (environmental noise).

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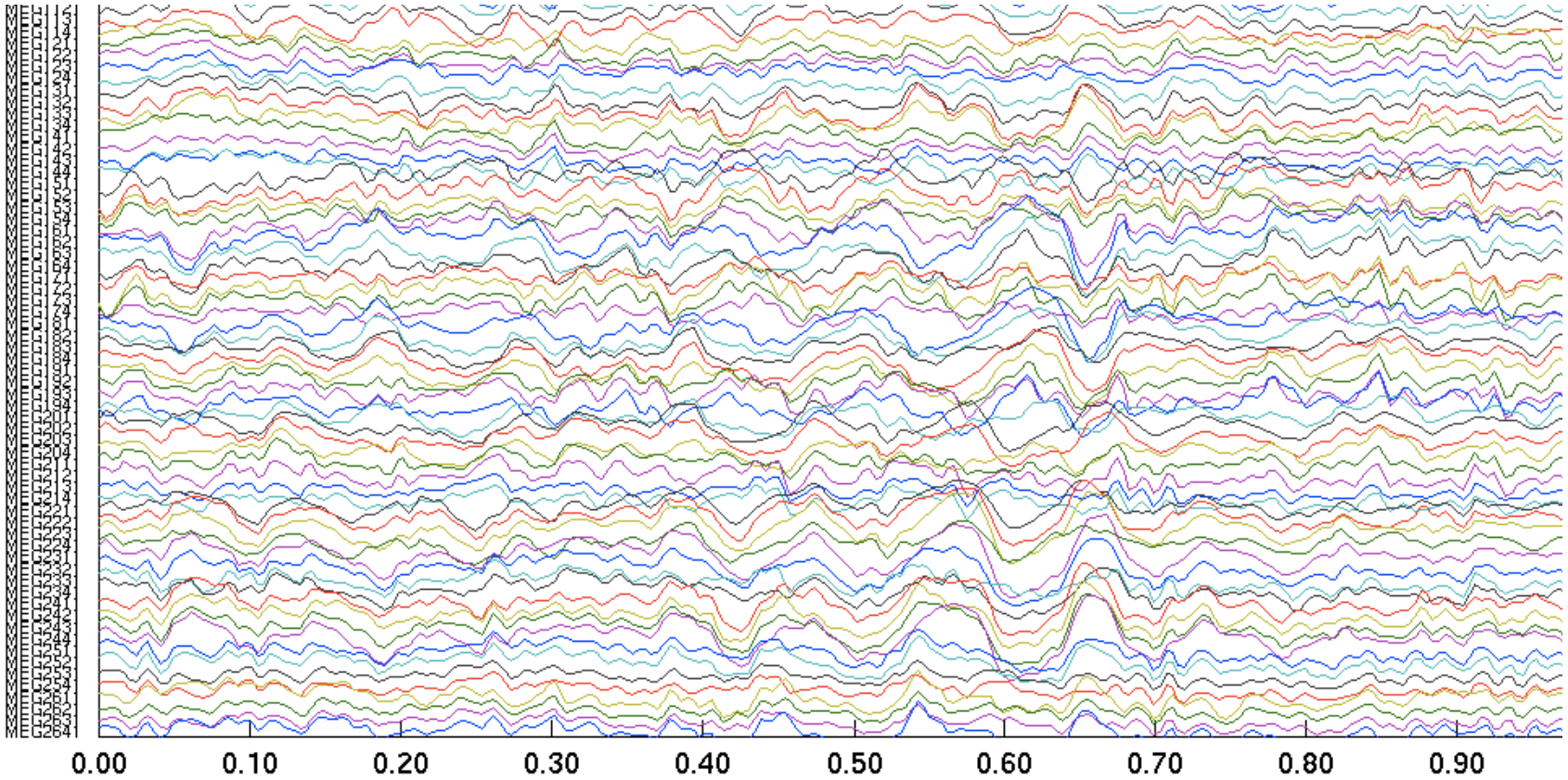

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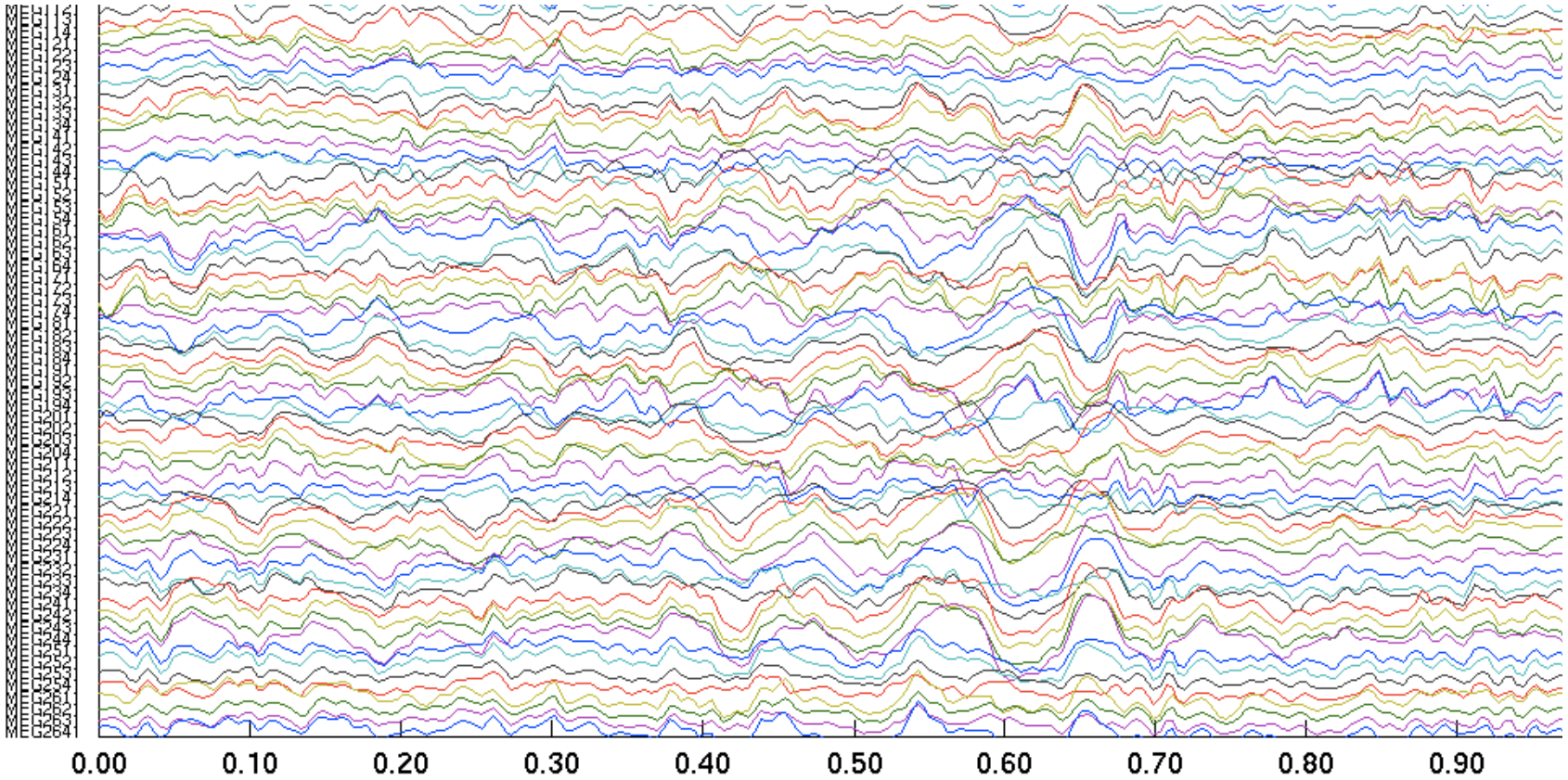
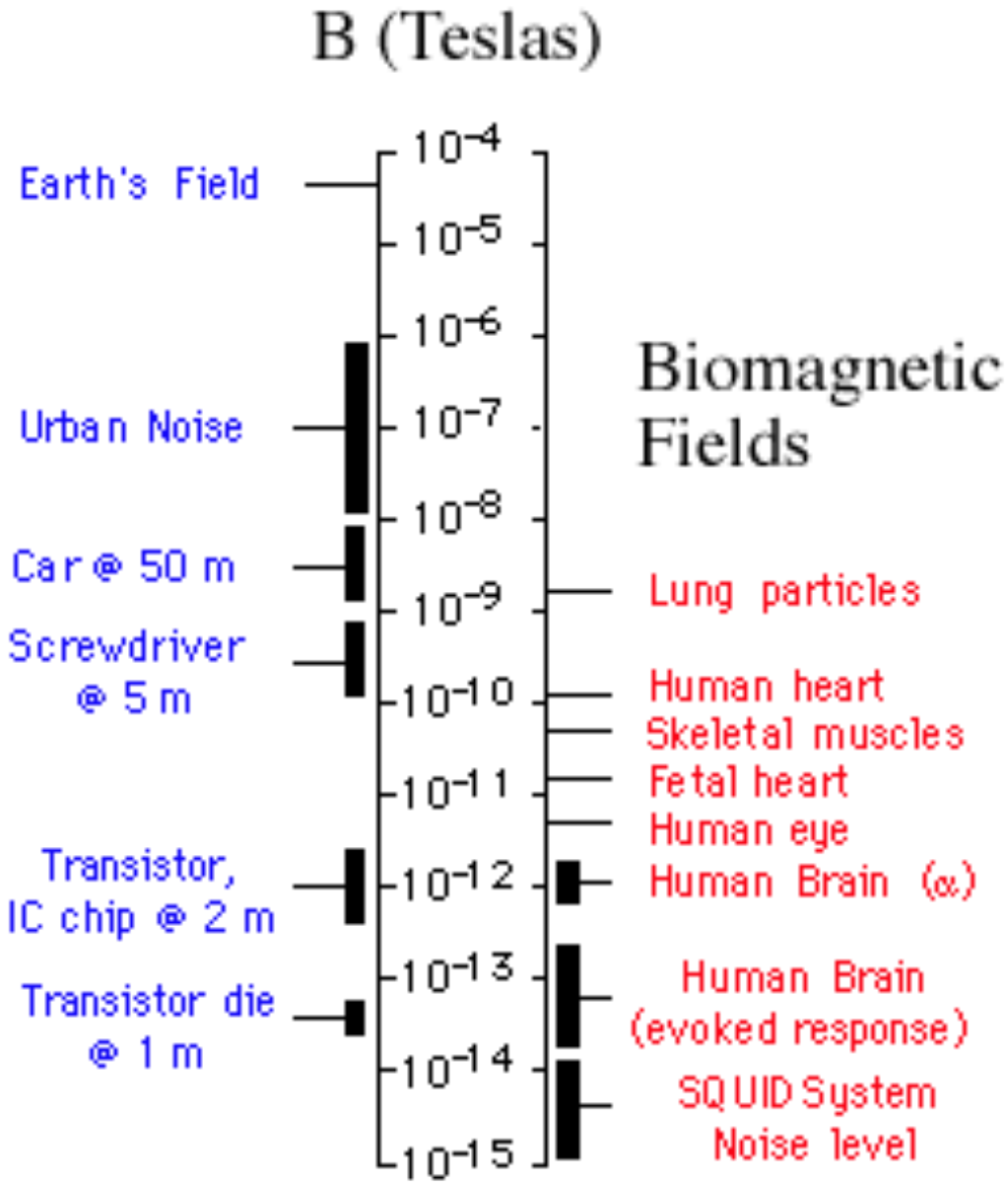


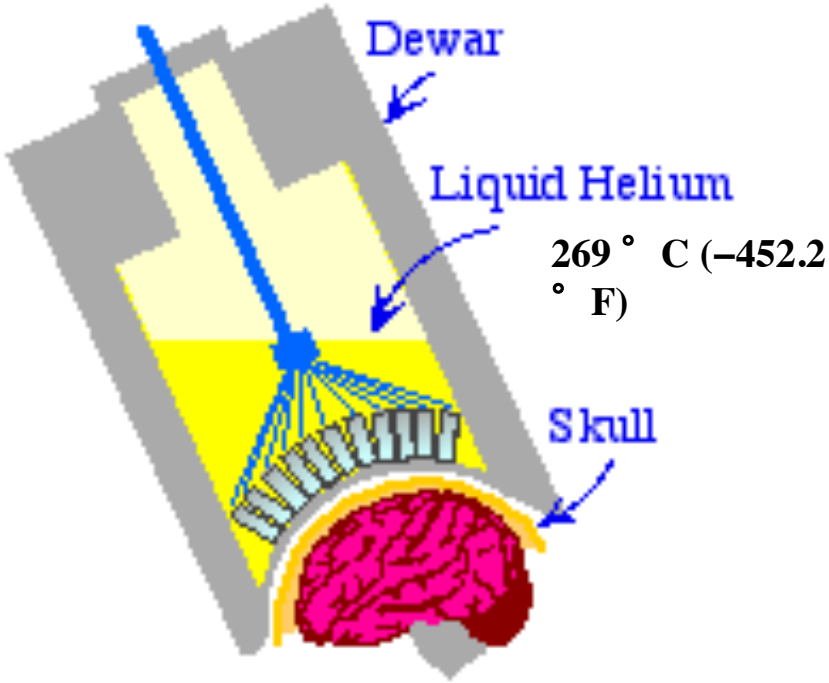
Magnetic Fields



The magnetic fields generated by neural activity are 100 million times smaller than the earth's magnetic field and 1 million times smaller than the magnetic fields produced in an urban environment.

How to capture the tiny MEG signal

Superconductive sensors



Magnetically shielded room

- Layers of mumetal blocking magnetic fields.

Reference channels

- Placed somewhere close to the head but far enough to not capture any brain activity.
- In data processing, signal correlated with the measurement of the reference channels is removed.

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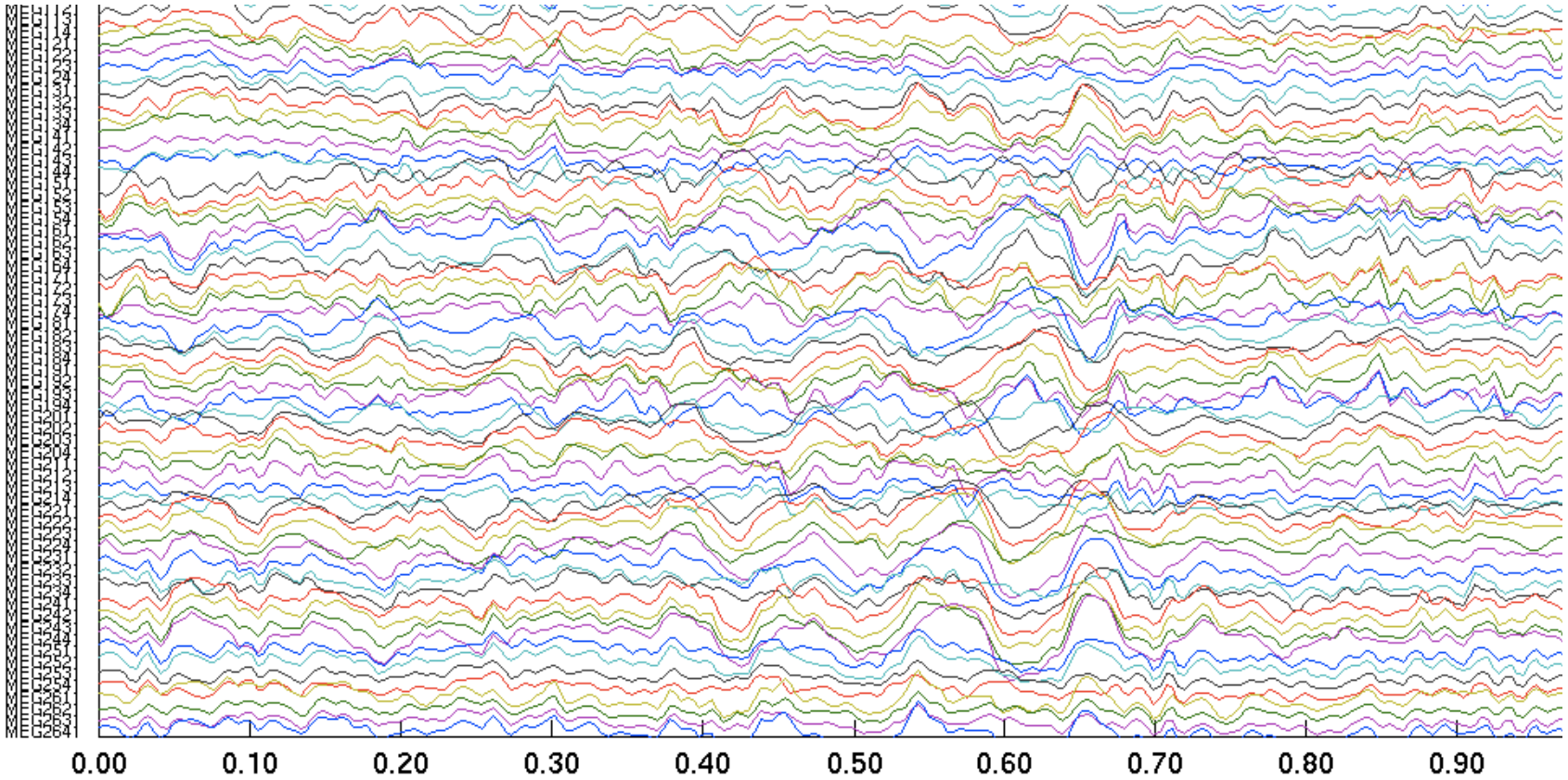


EEG vs. MEG

Complementary,
but differ in
price, resolution and coverage

Price

- Price: EEG is much cheaper (and therefore much more common) than MEG
  - **EEG: < $100K**
  - **MEG: ~$2M**
- Capturing the tiny magnetic fields associating with neural currents is much harder than measuring electric potentials from the scalp.
  - **Overcoming this physics challenge gets pricy.**

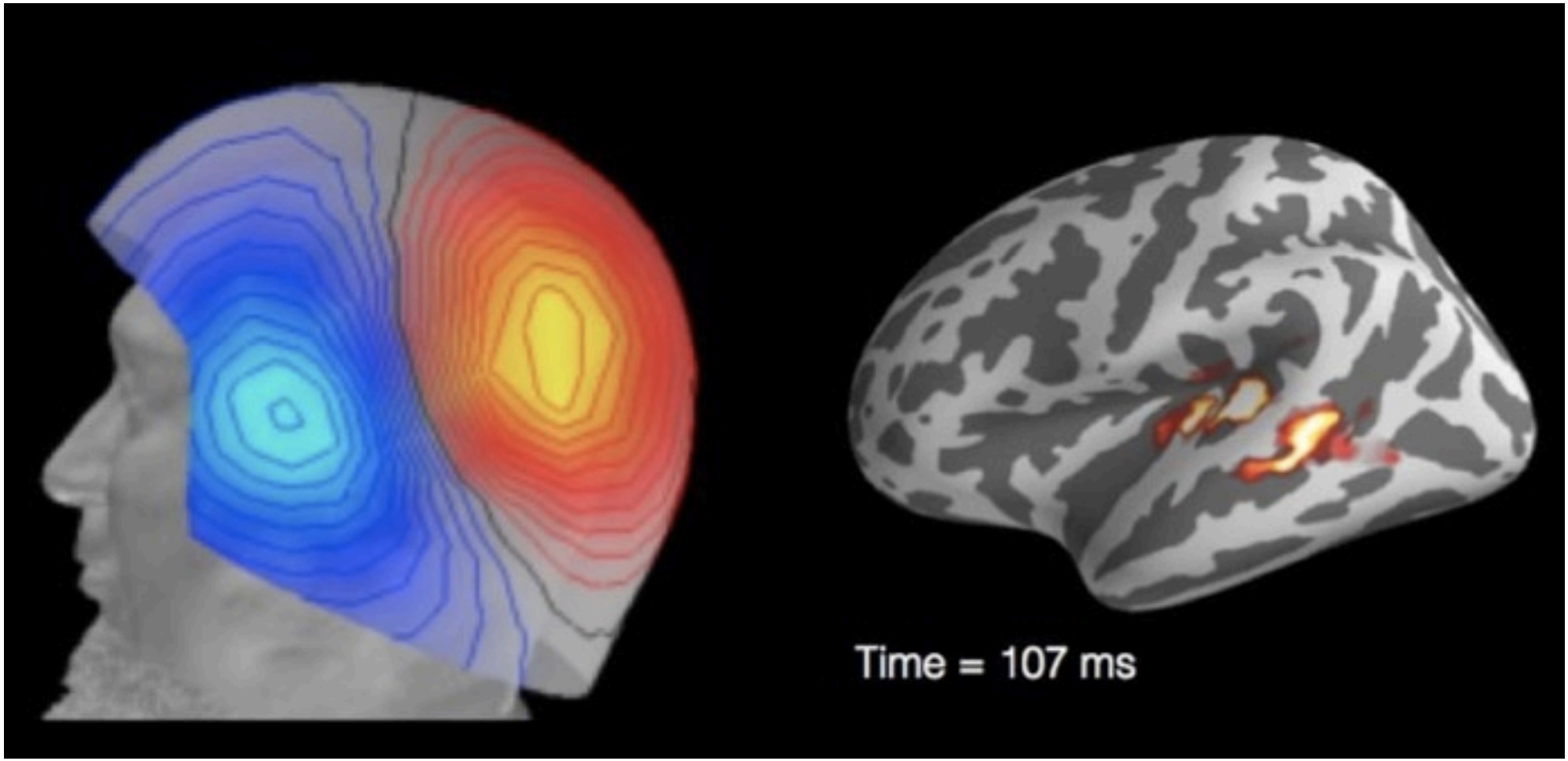
Resolution

- Both have excellent temporal resolution, but the spatial resolution of MEG is much better than that of EEG.
  - **EEG**
    - Different tissues and skull all differ in their electrical conductivity. This can distort the electric potential in many ways before it reaches the scalp. The distribution of electric potentials on the scalp cannot easily be used to model where the generating currents are located.
  - **MEG**
    - Magnetic fields pass through the different structures of the brain and head undistorted. Localization of the generating currents is possible (and routine)
    - Spatial resolution ~2cm depending on depth of source

Resolution

Magnetic field

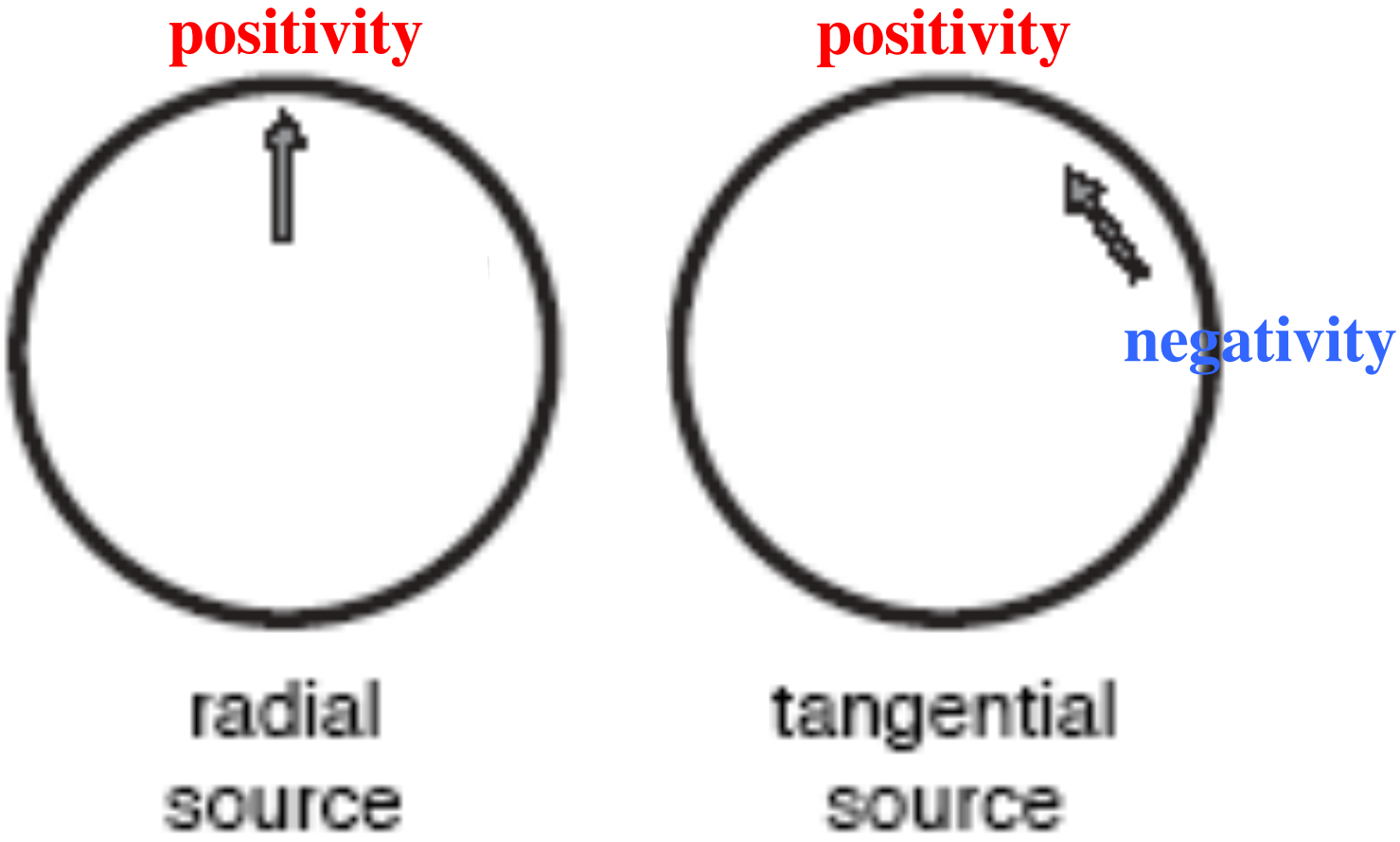
Source reconstruction



MNE software

Coverage

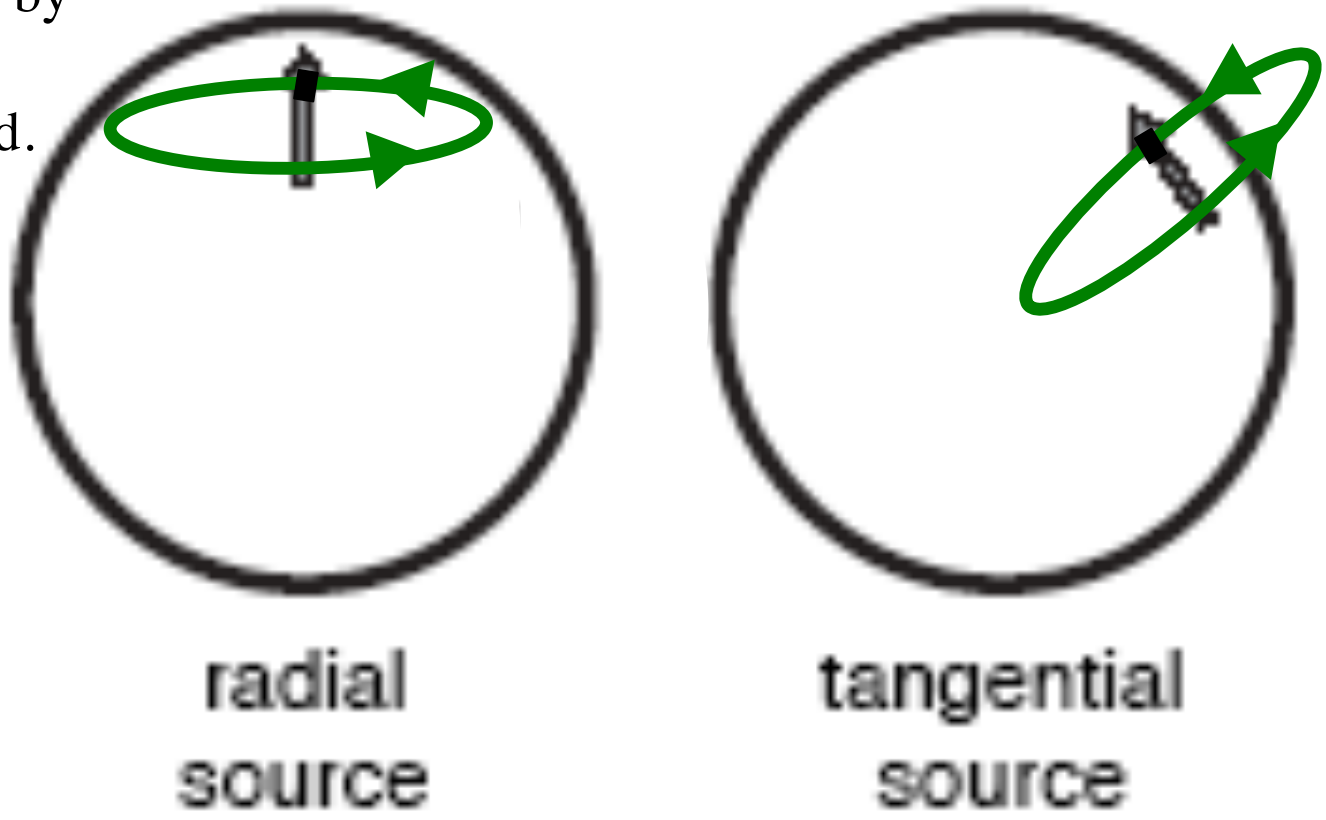
- Current orientation matters for MEG but not for EEG.



Coverage

- Current orientation matters for MEG but not for EEG.

Cannot be seen by MEG sensors outside the head.



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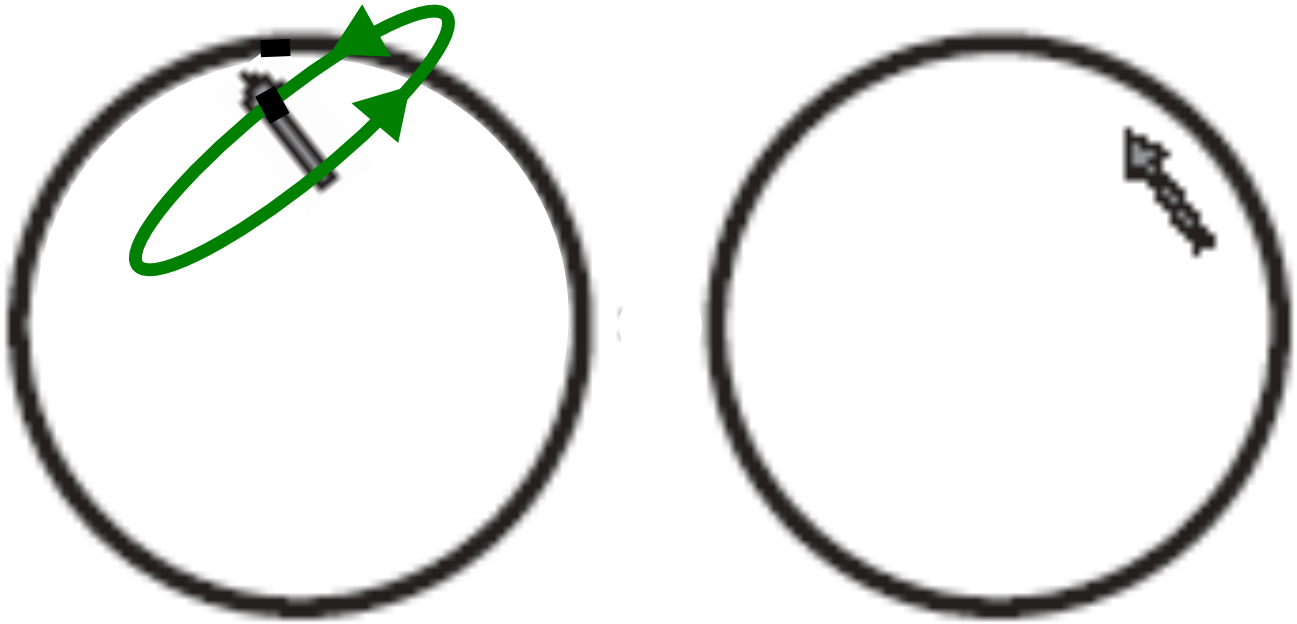


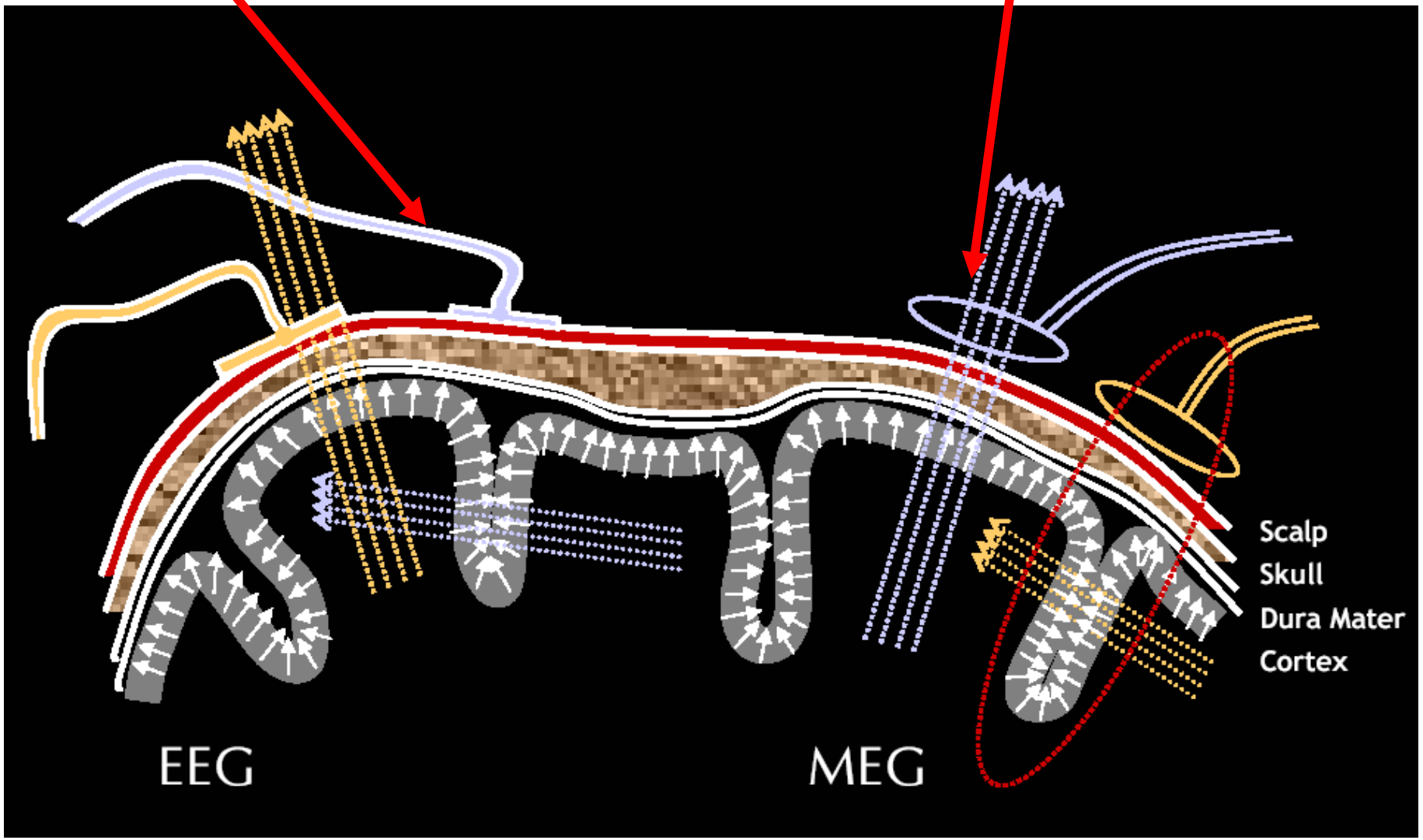
Even a small tangential component can make the field "MEG-visible"

Coverage

- Current orientation matters for MEG but not for EEG.
- MEG has a tiny blind spot on the very tops of gyri while EEG doesn't.
- Signal dominated by different currents. Different "sweet spots."
  - **EEG signal dominated by activity in gyri. Closest to electrodes.**
  - **MEG activity dominated by activity in sulci. Yields the best magnetic field orientation.**

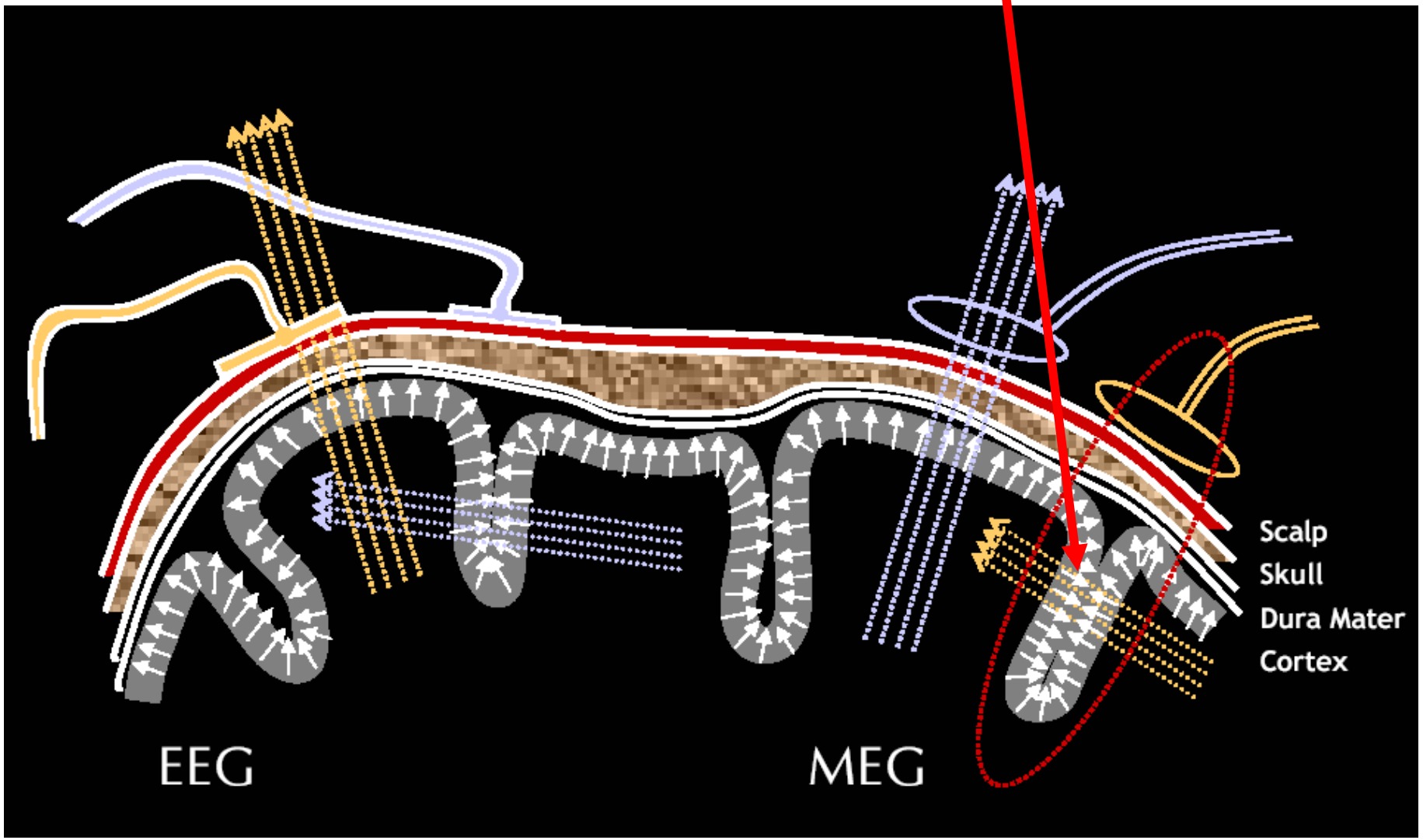
MEG sensors outside the head, in a tank containing liquid helium to enhance superconductivity

EEG electrodes on the scalp



Source: http://www.allgpsy.unizh.ch/graduate/mat/180102/Lecture1.pdf

MEG signal is dominated by currents oriented tangential to the skull.



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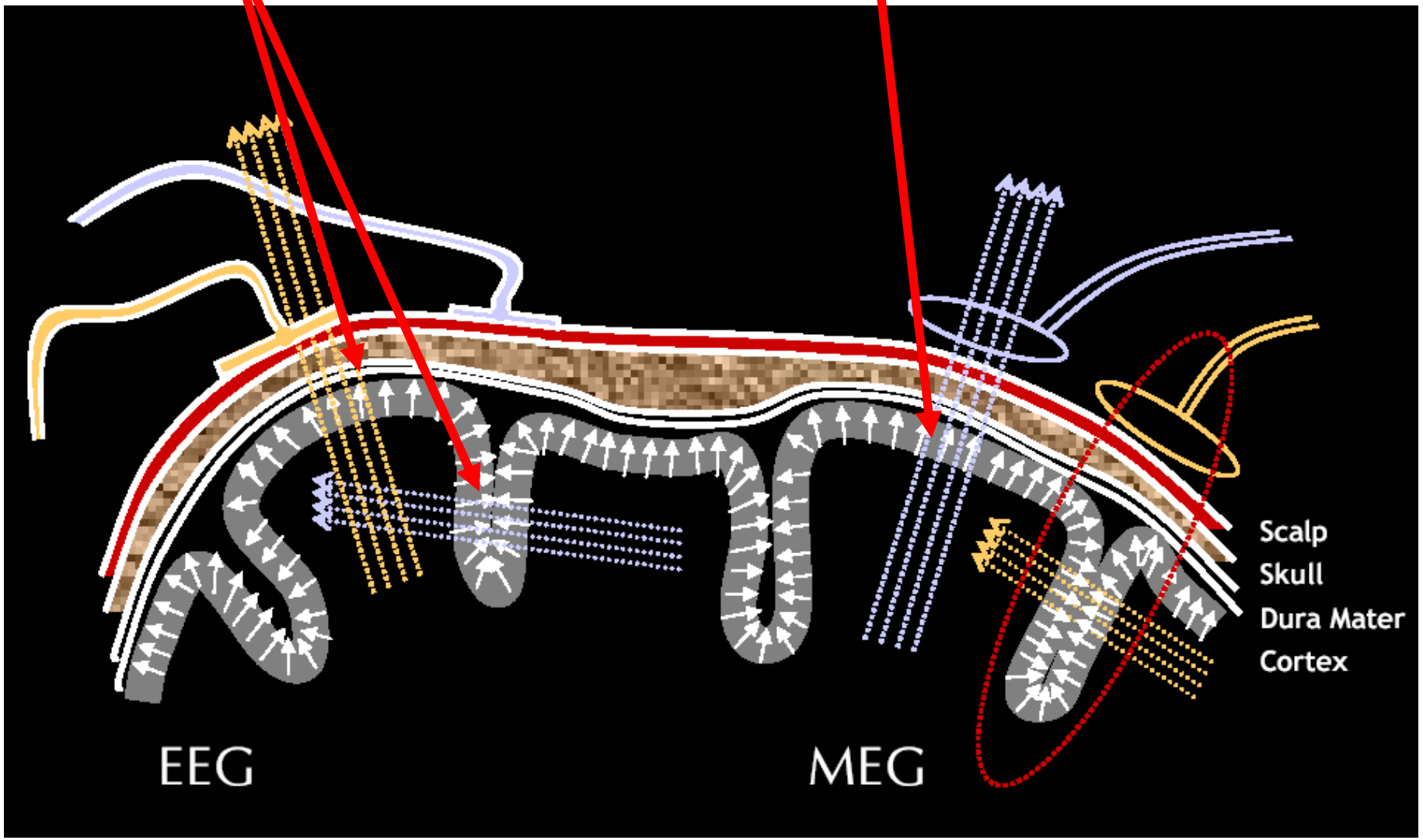
EEG picks up tangentially and radially oriented currents equally but the ones on tops of gyri are closest to electrodes.

Currents oriented perfectly radial to the skull are missed in MEG. But there is very little signal that is so perfectly radial.



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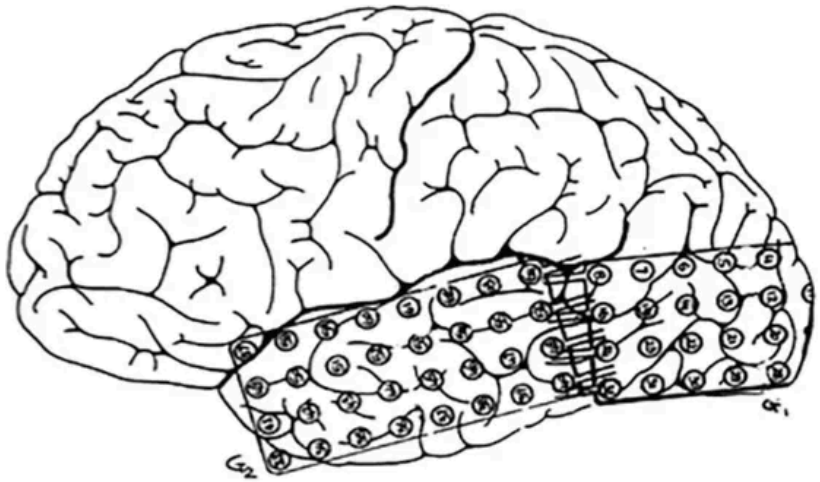
Bottomline

- EEG is cheap, widely available, and offers excellent temporal resolution.
- MEG offers the **best combination of both temporal and spatial resolution of all non-invasive cognitive neuroscience techniques**, justifying the price.
- The resolution of MEG can only be rivaled by **iEEG**: intracranial EEG recorded directly from the cortex (or deeper structures) of patients who are about to undergo brain surgery.
  - **Invasive**
  - **But offers the only research opportunity we have for near perfect spatial + temporal resolution in humans.**



Electrode grid on cortex