Application of MEG / EEG in Medicine or Neuroscience

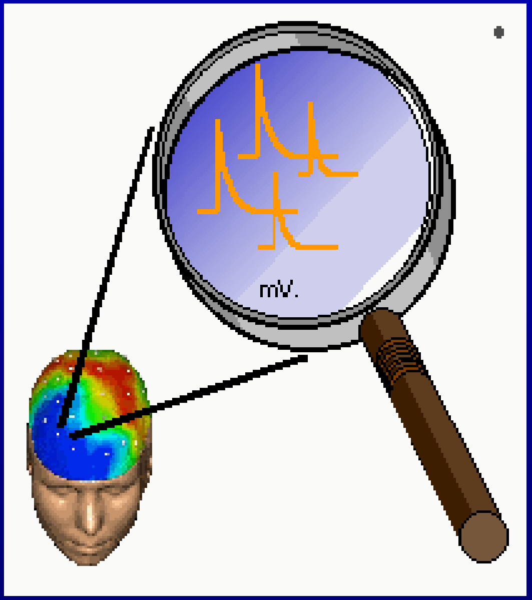
Electro
Encephalo
Graphy

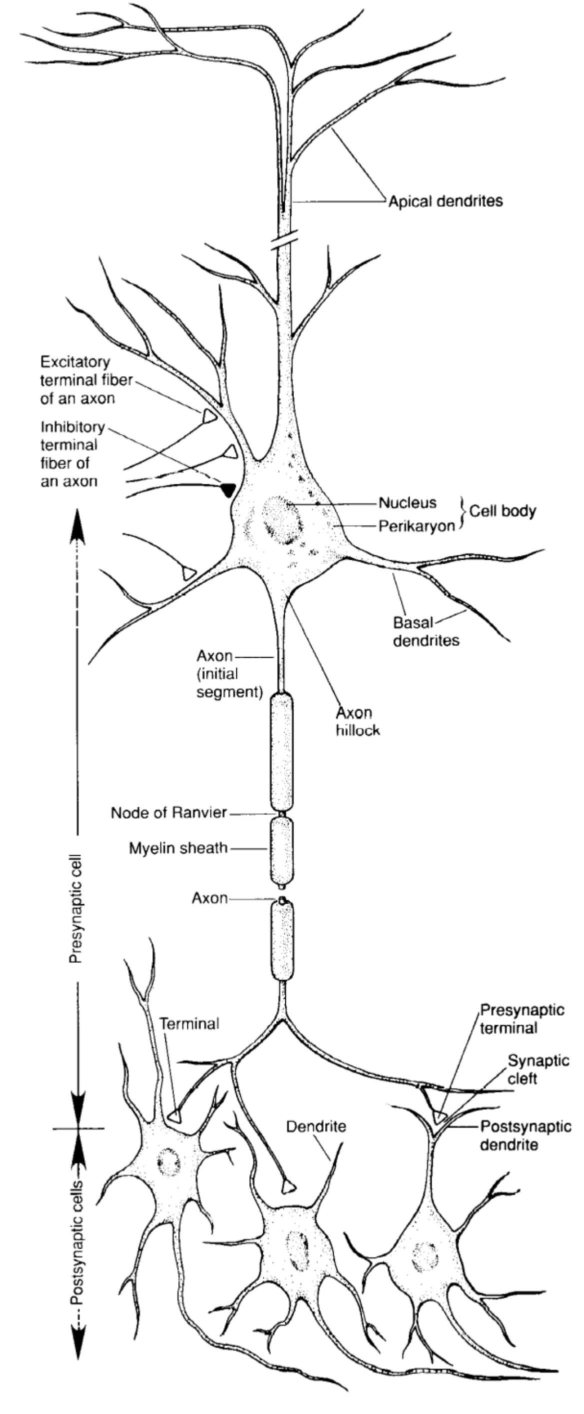
Magneto
Encephalo
Graphy

Slides: Free University A'dam

Application of MEG/EEG in Medicine or Neuroscience

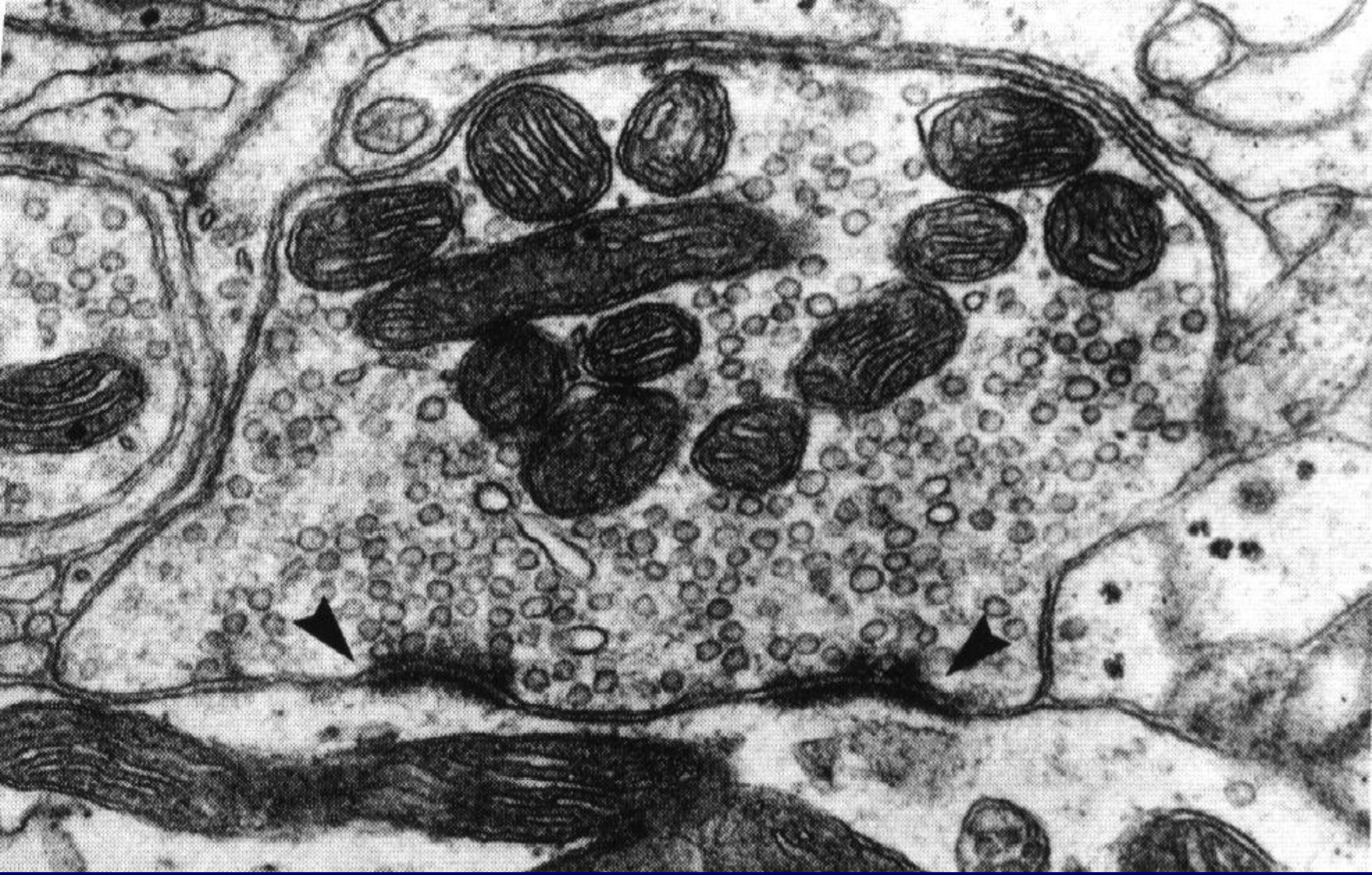
- Introduction to EEG & MEG
- Instrumentation
- Analysis
- Examples
  - – Magnetic Source Imaging
  - – Localizing Rhytmic Activity



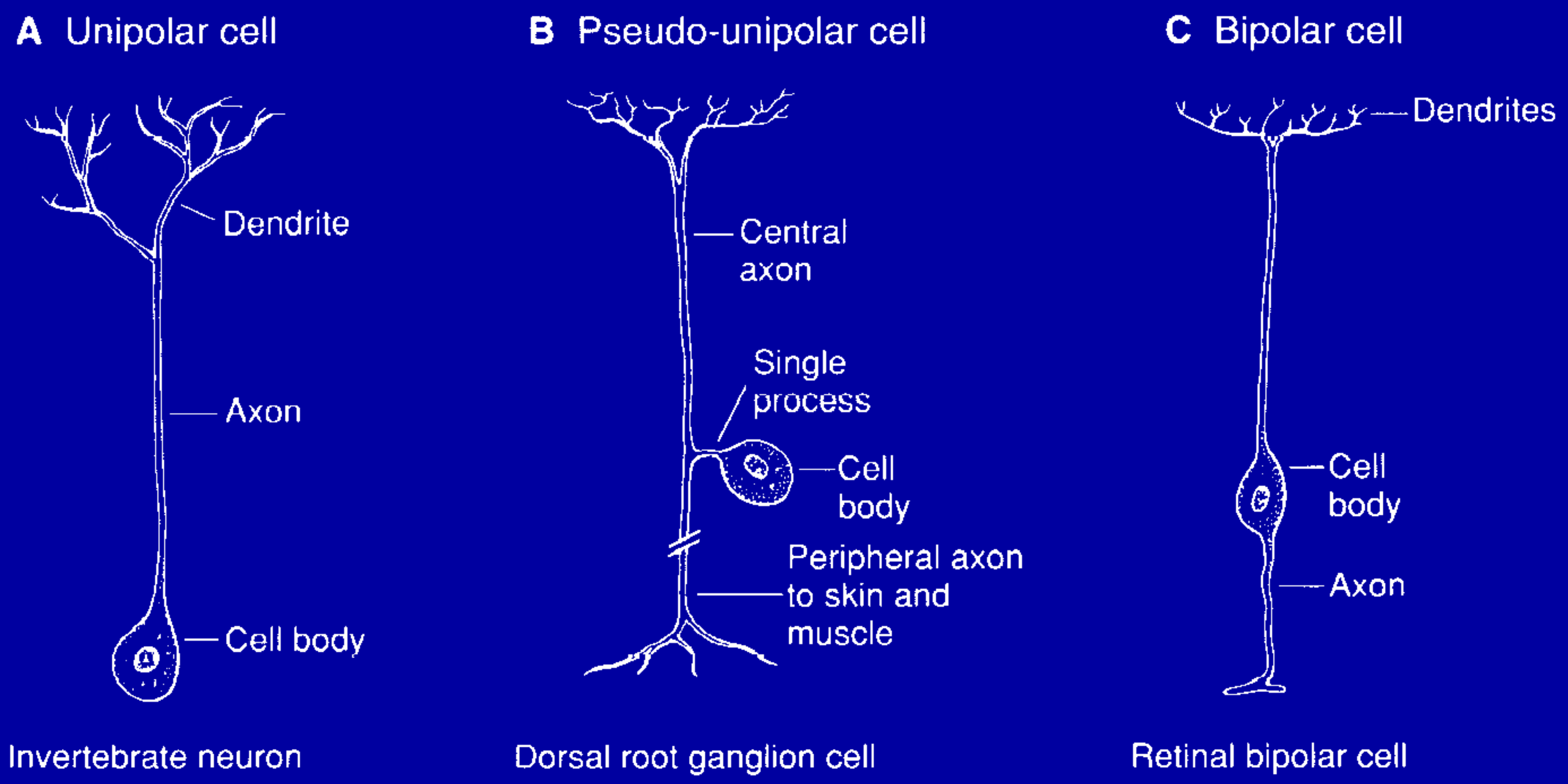


A nervecell consists of a **soma** with input **dendrites**. On both **synapses** project as little pedicles.

The **axon** is the output. Conduction speed is greatly improoved by the **nodes of Renvier** in the **myelin sheeth**.

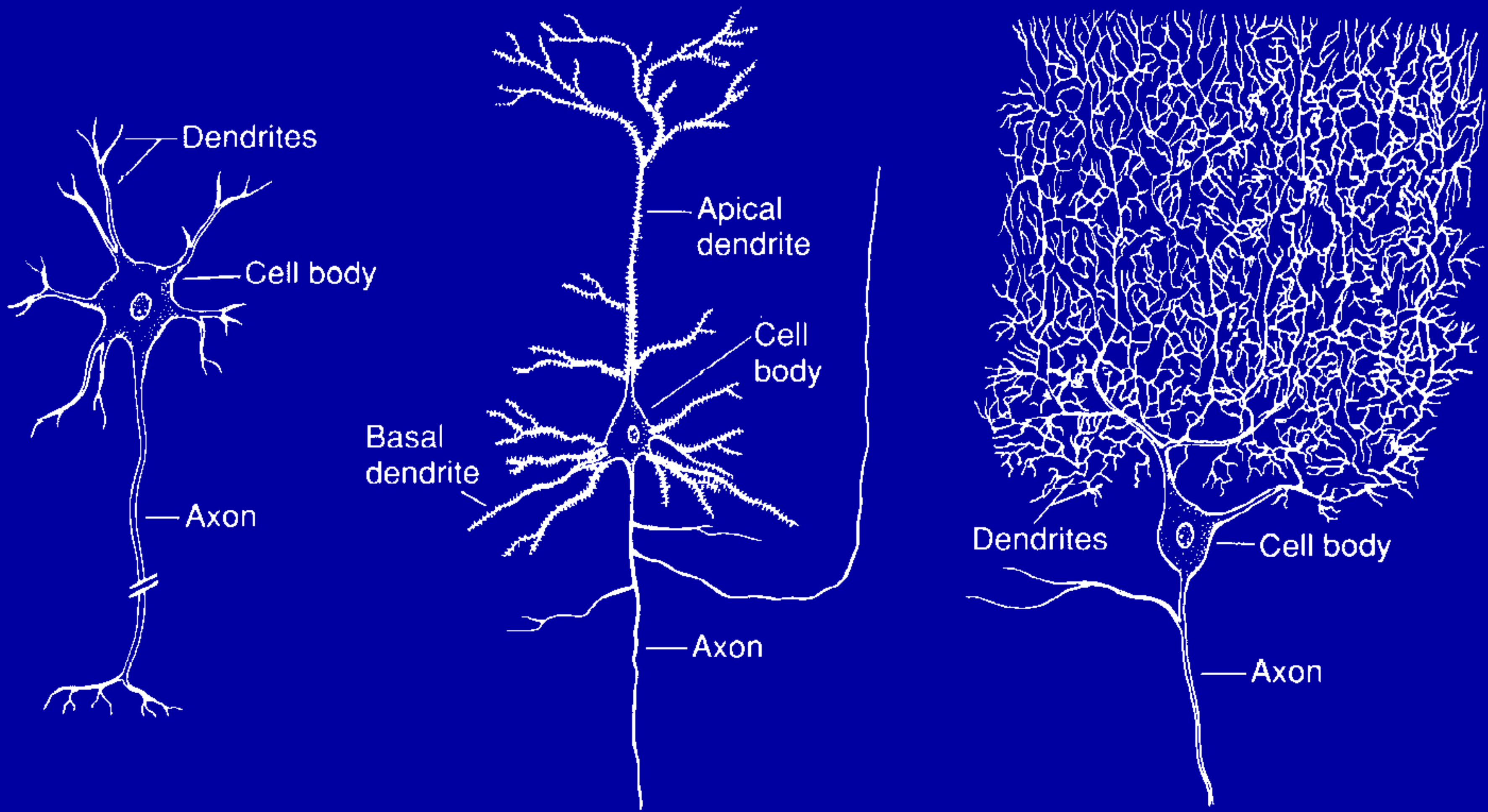


Synapses:
At the synaptic cleft little follicles of neurotransmitter are released



Nerve cell types

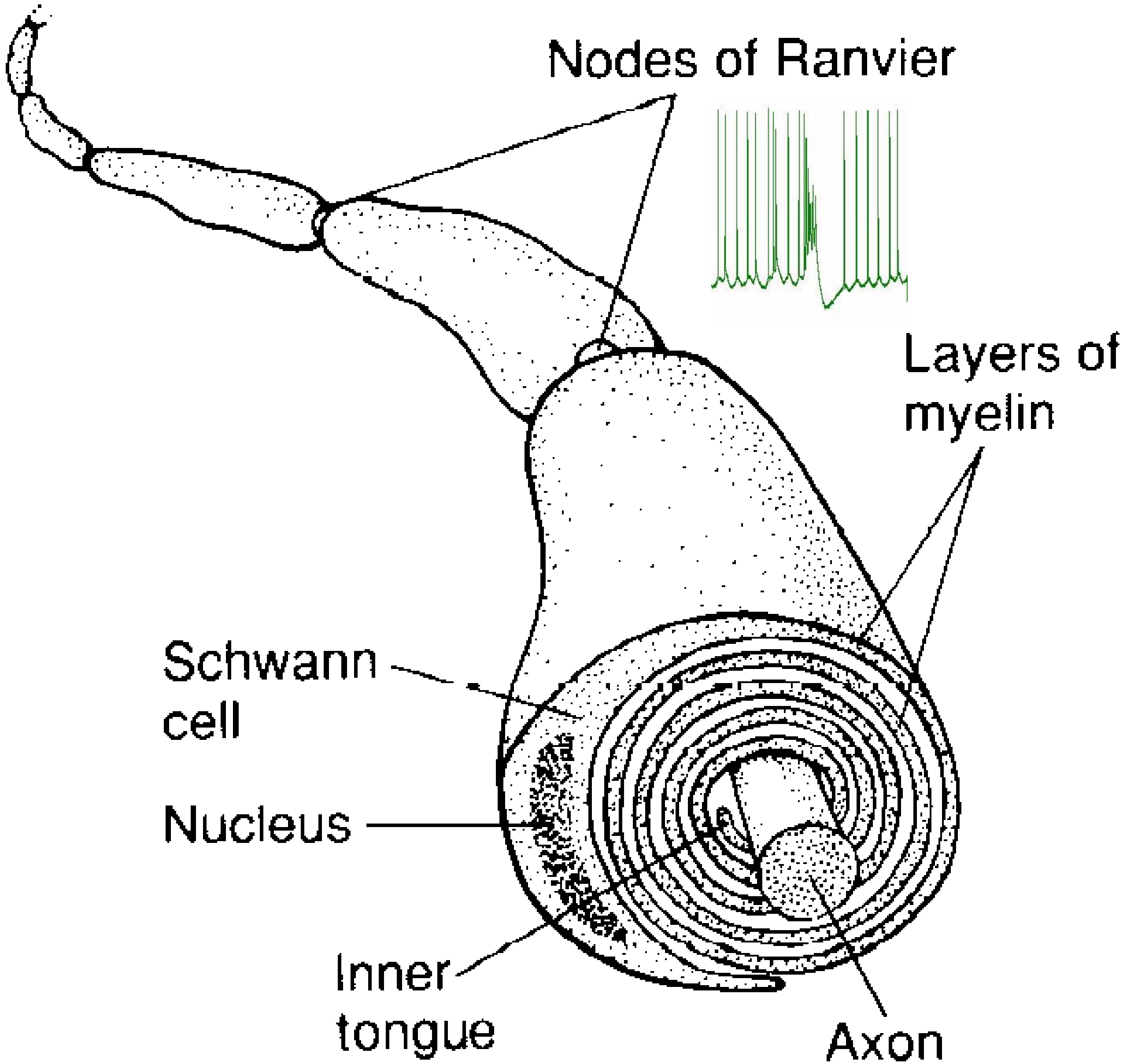
D Three types of multipolar cells

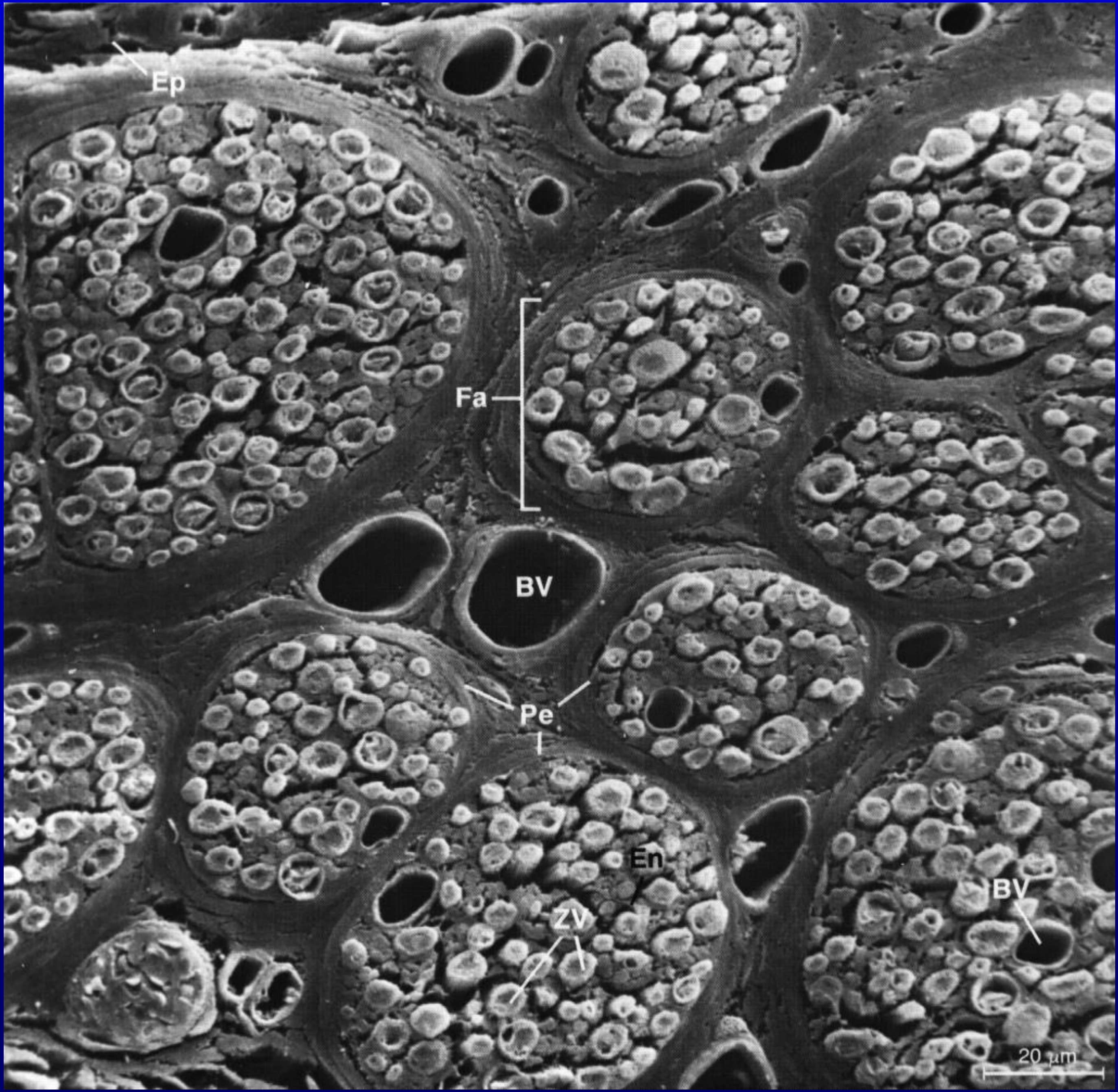


Spinal motor neuron

Hippocampal pyramidal cell

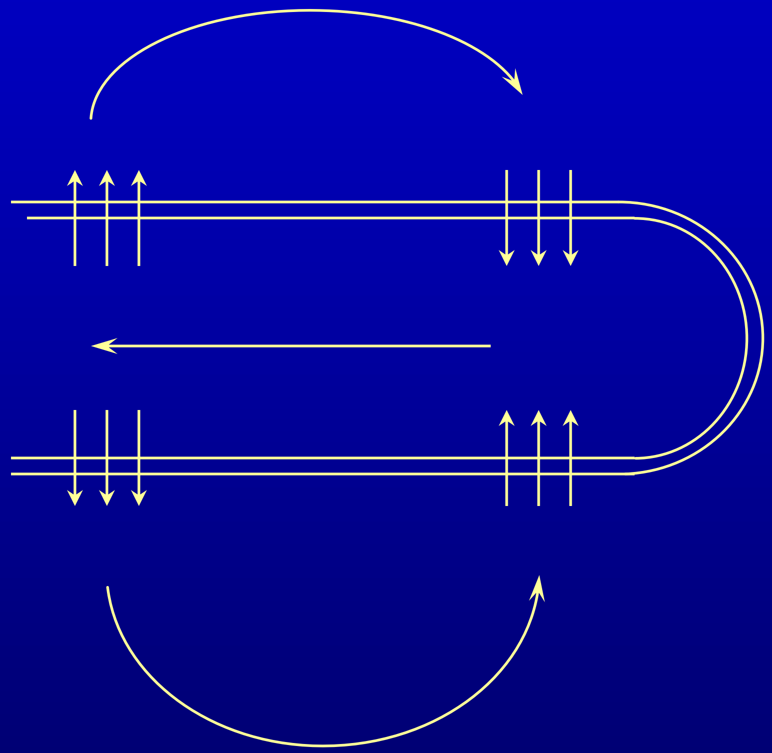
Purkinje cell of cerebellum


Nodes of Ranvier
Layers of myelin
Schwann cell
Nucleus
Inner tongue
Axon

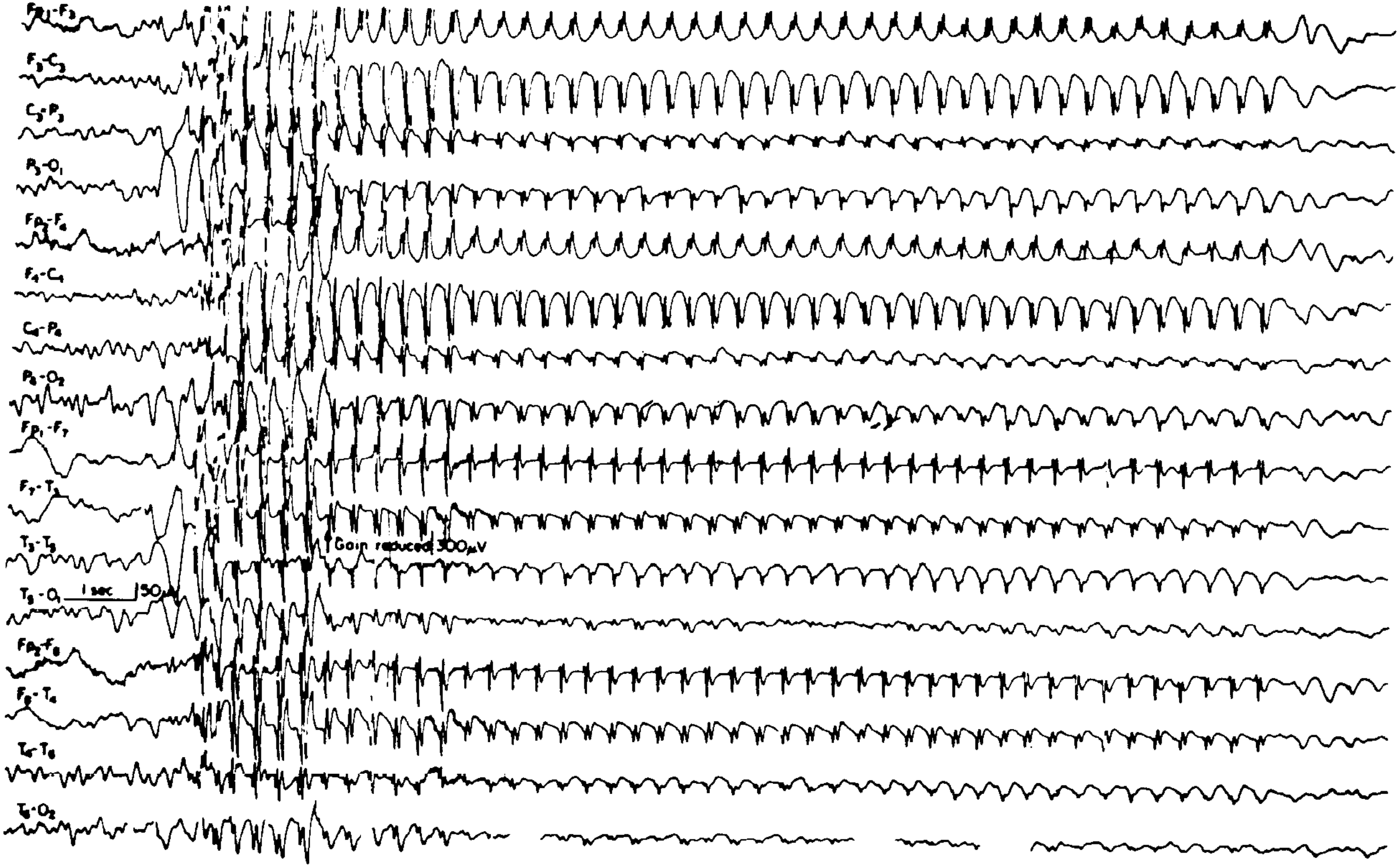


A peripheral nerve bundle

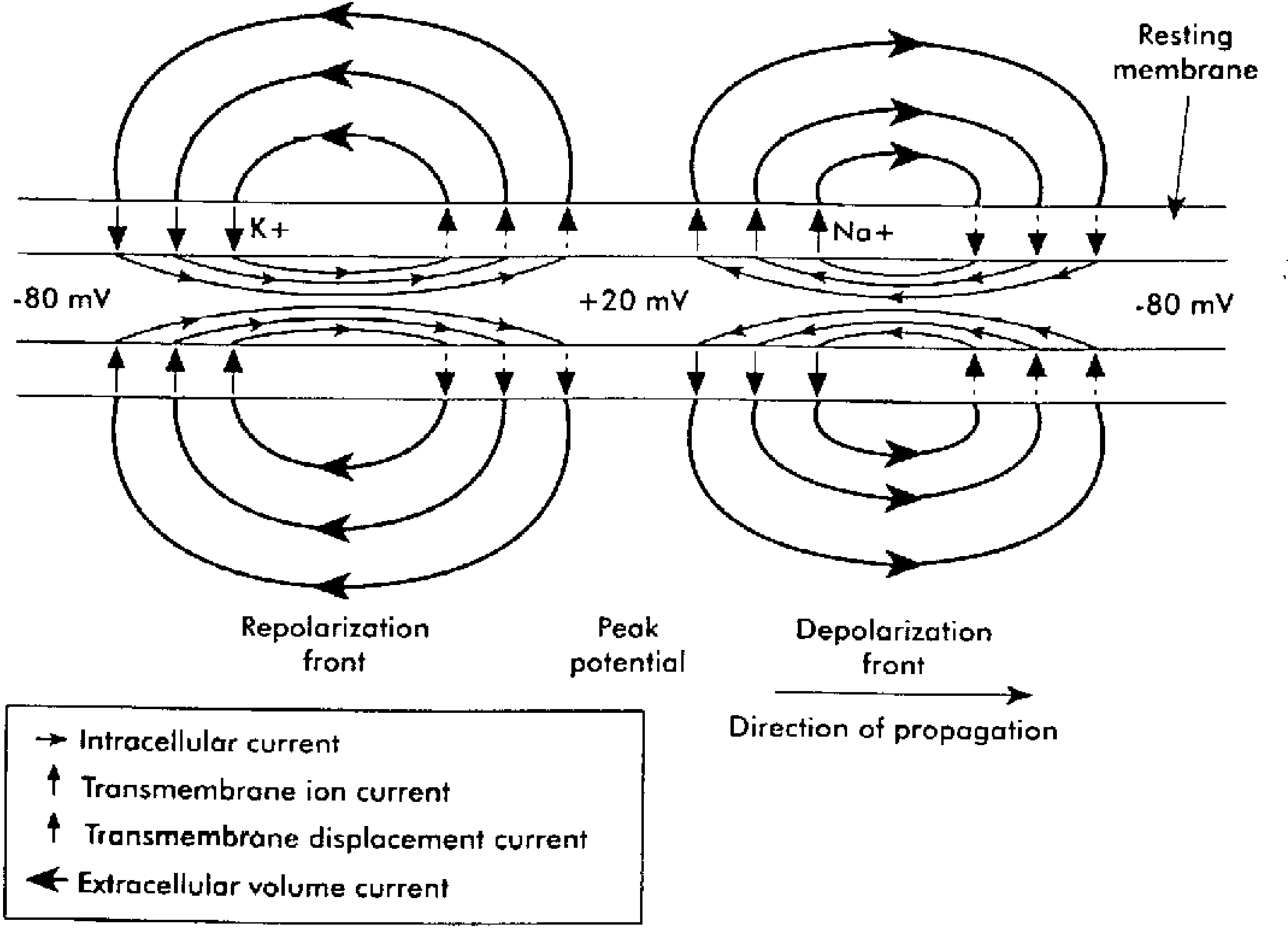
Fysiological basis of EEG and MEG



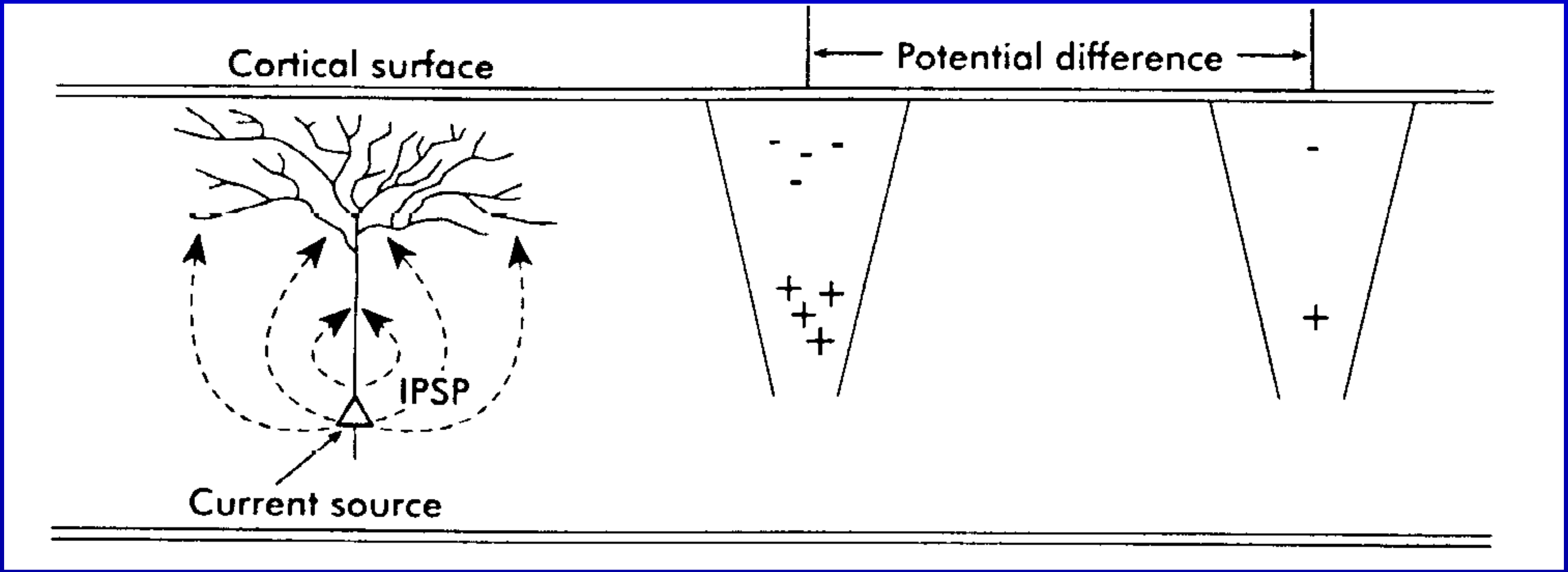
- Transmembrane current
- Intracellular current
- Extracellular current



Example of an EEG of a Petit Mal epileptic seizure, showing characteristic 3 Hz spike/wave complexes.

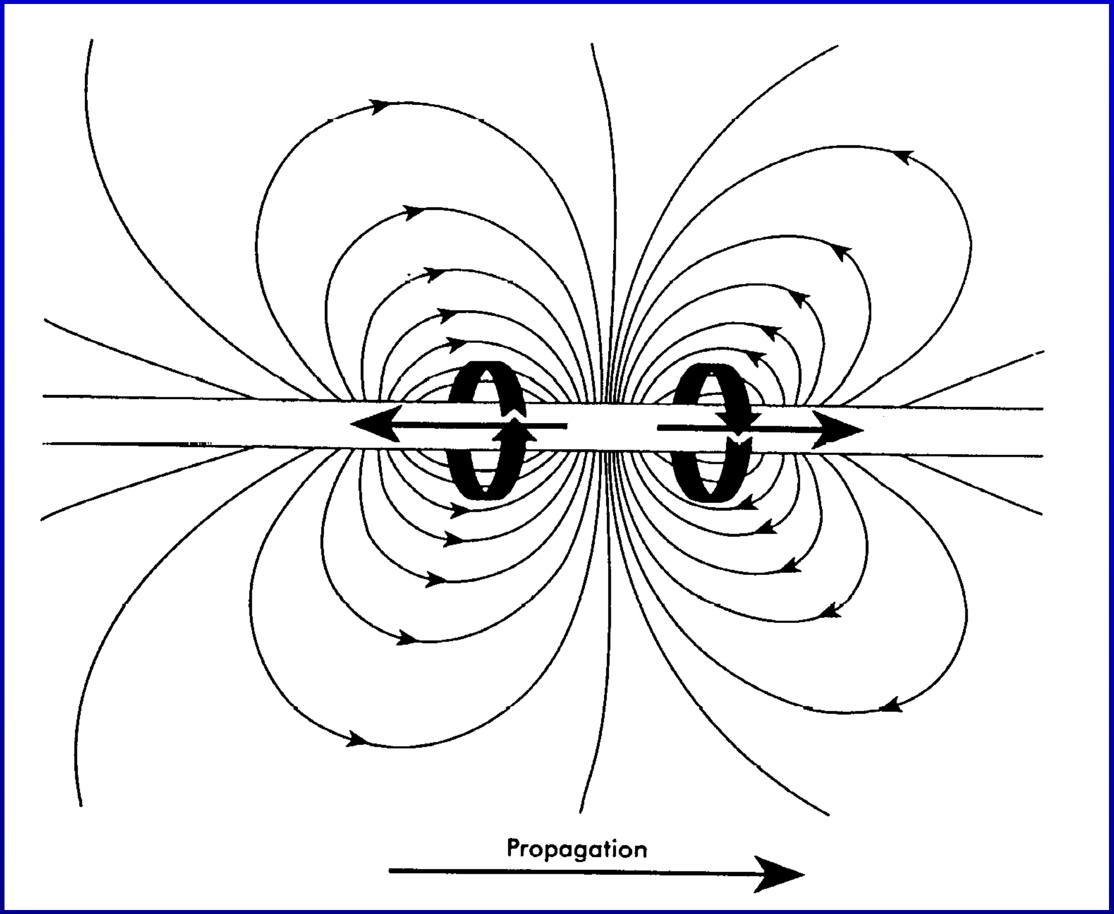


Resting membrane
K+
Na+
-80 mV
+20 mV
-80 mV
Repolarization front
Peak potential
Depolarization front
Direction of propagation
Intracellular current
Transmembrane ion current
Transmembrane displacement current
Extracellular volume current



The surface potential established by intracranial neural activity decresases with distance from the source.

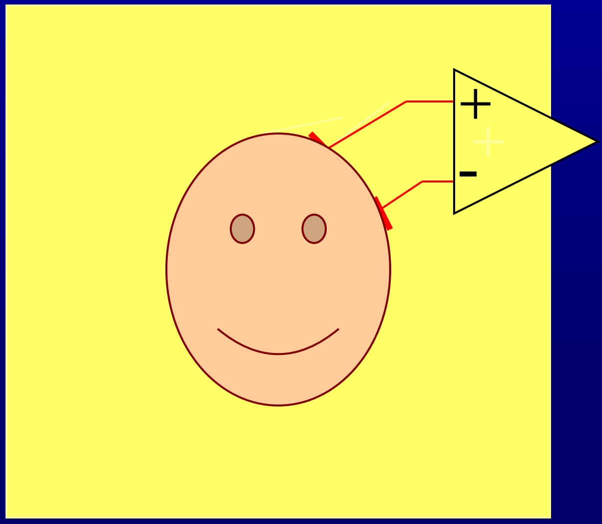
For dipolar sources, the potential falls as a function of the square of the distance. EEG measures the potential differences between two recording sites.



Action potentials are associated with a leading depolarization front and a trailing repolarizing front. The associated current configuration is quadrupolar, and at a distance, the electrical field generated by each of the opposing current components mostly cancel each other.

Introduction EEG

EEG measures the potential difference on the skin surface due to the backflowing current at the surface.

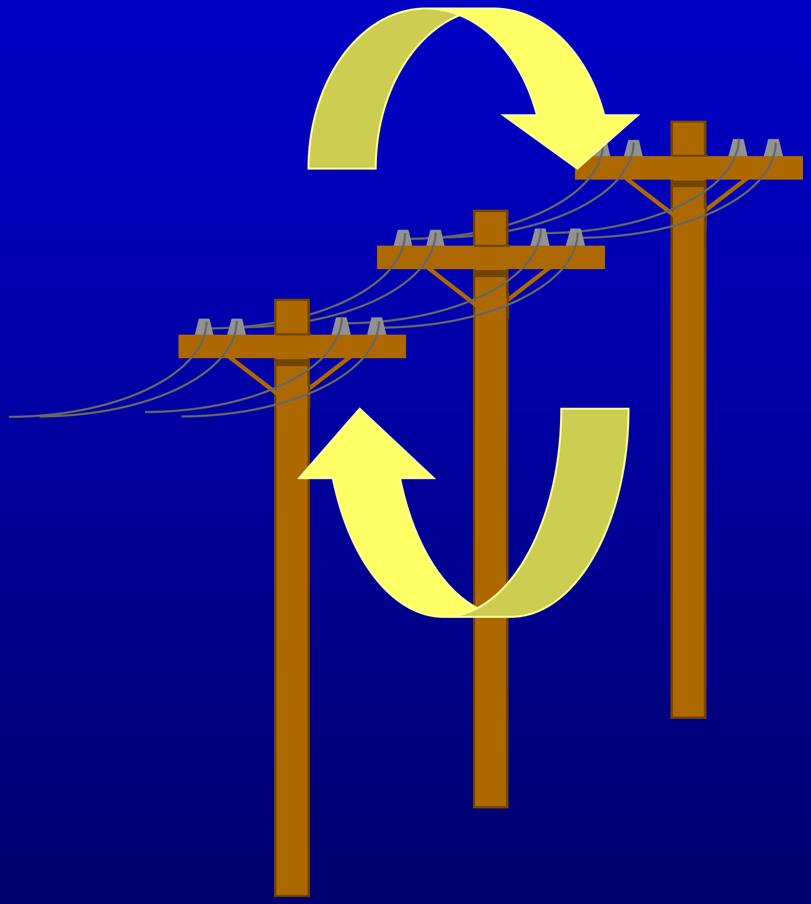


Introduction to MEG

- MEG records the gradient of the Magnetic Induction

$$\frac{d}{d\vec{x}}\vec{B}(\vec{x},t)$$

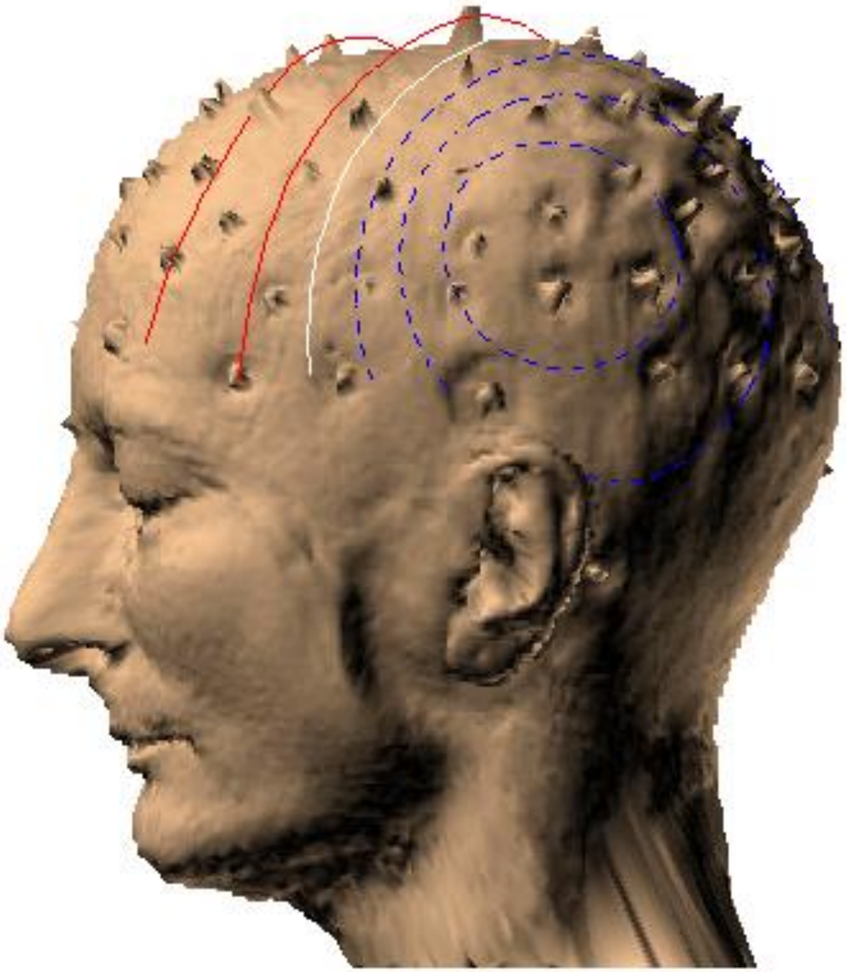
The Magnetic Induction results from electrical currents



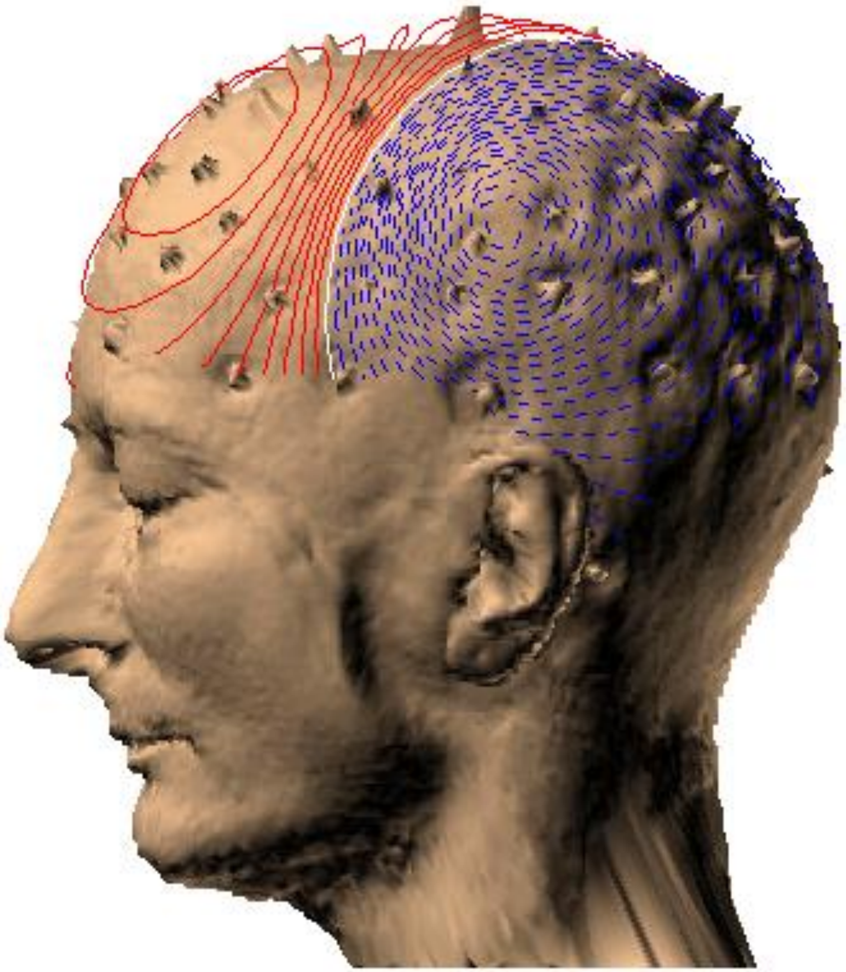
Introduction to MEG

Electrical current in the brain

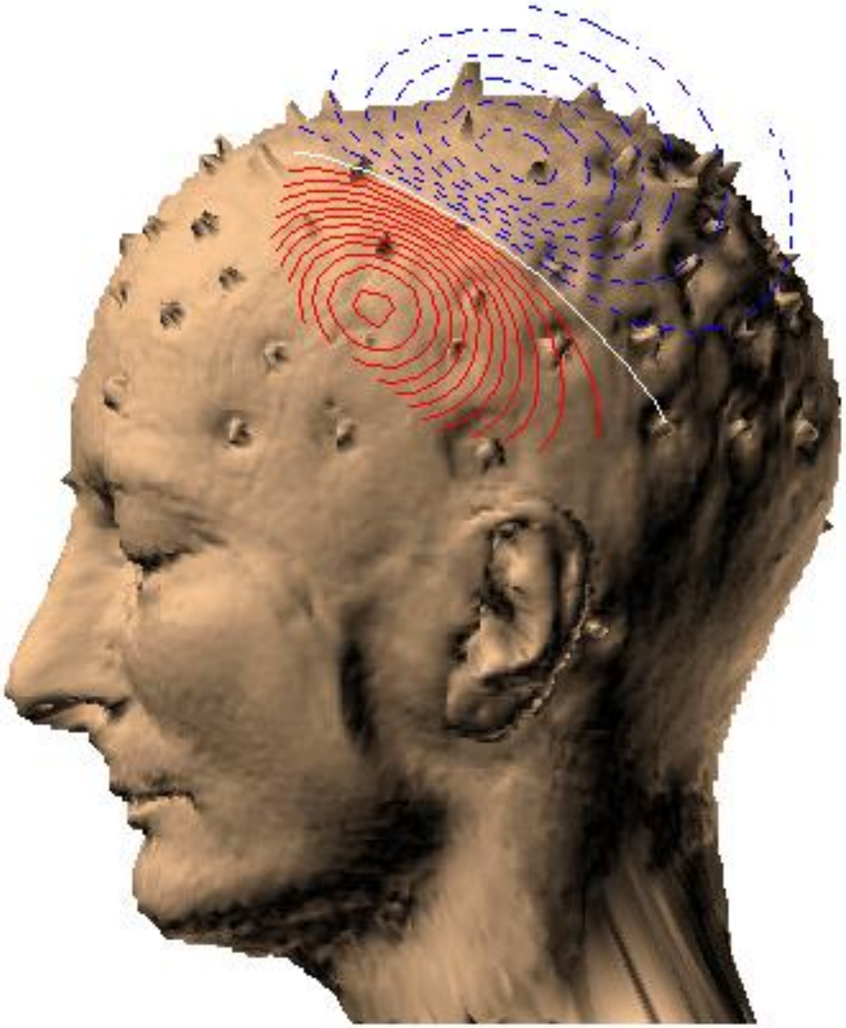
- spatial components
  - transmembrane current
  - intra-cellulair current ← MEG EEG
  - extra-cellulair current ← EEG
- temporal components
  - activation of synapses ← MEG EEG
  - spiking activity



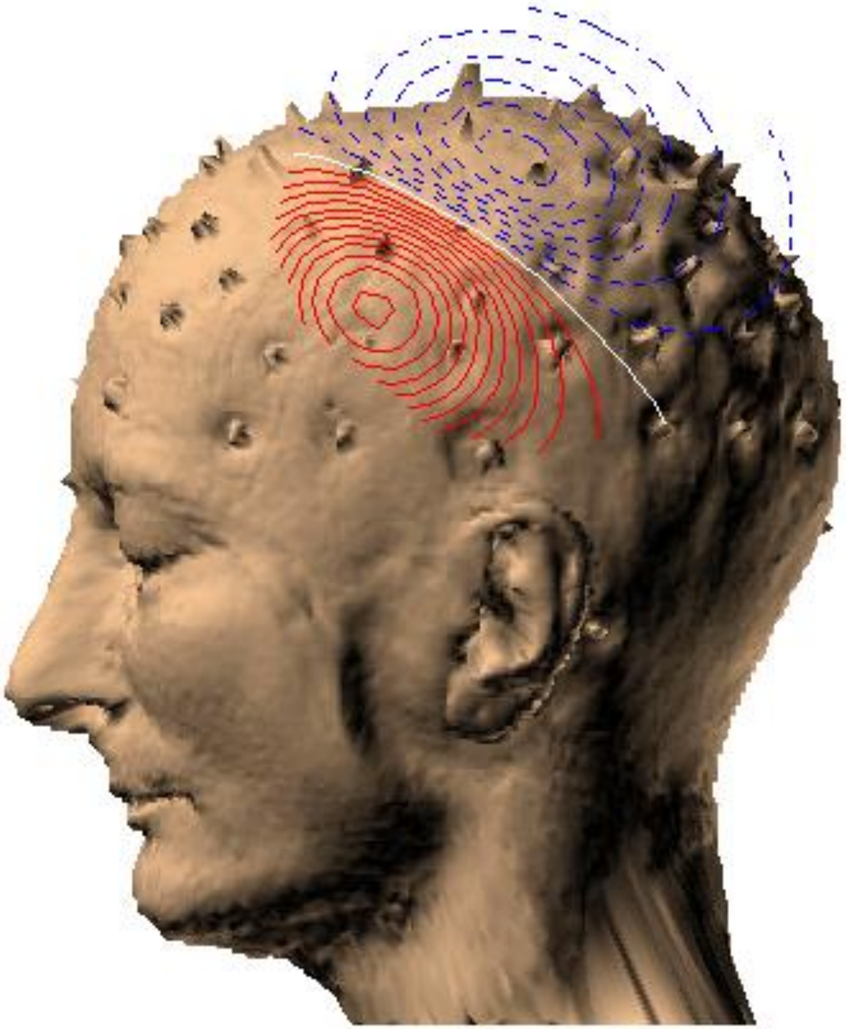
EEG



EEG “without” skull



MEG “without” skull



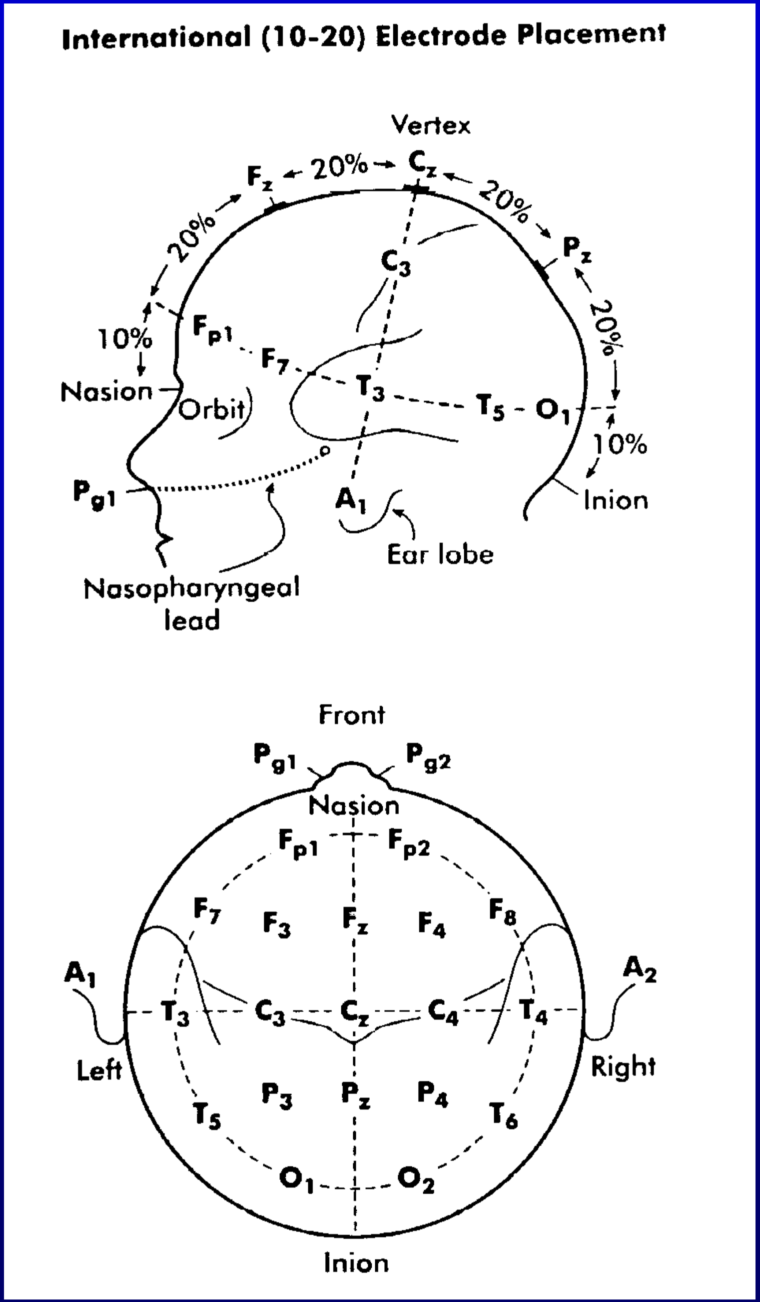
MEG

How the EEG is recorded

- Bipolar or Monopolar derivation
  - a-b; b-c; c-d; d-e; etc.
  - a-ref; b-ref; c-ref; d-ref; etc.
- Clinical routine: 10-20 system with 21 electrodes
- Recording problems:
  - Skin resistance & skin capacitance
  - Mechanical
  - DC recording
  - noise from bad grounding

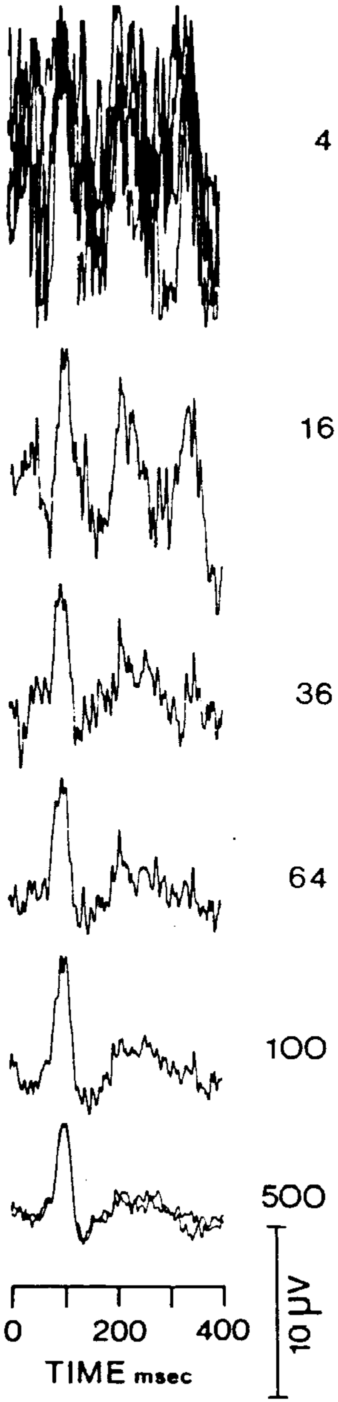
Modern EEG equipment

- up to 256 leads
- small and portable
- fully digitized
- battery operated
- cheap



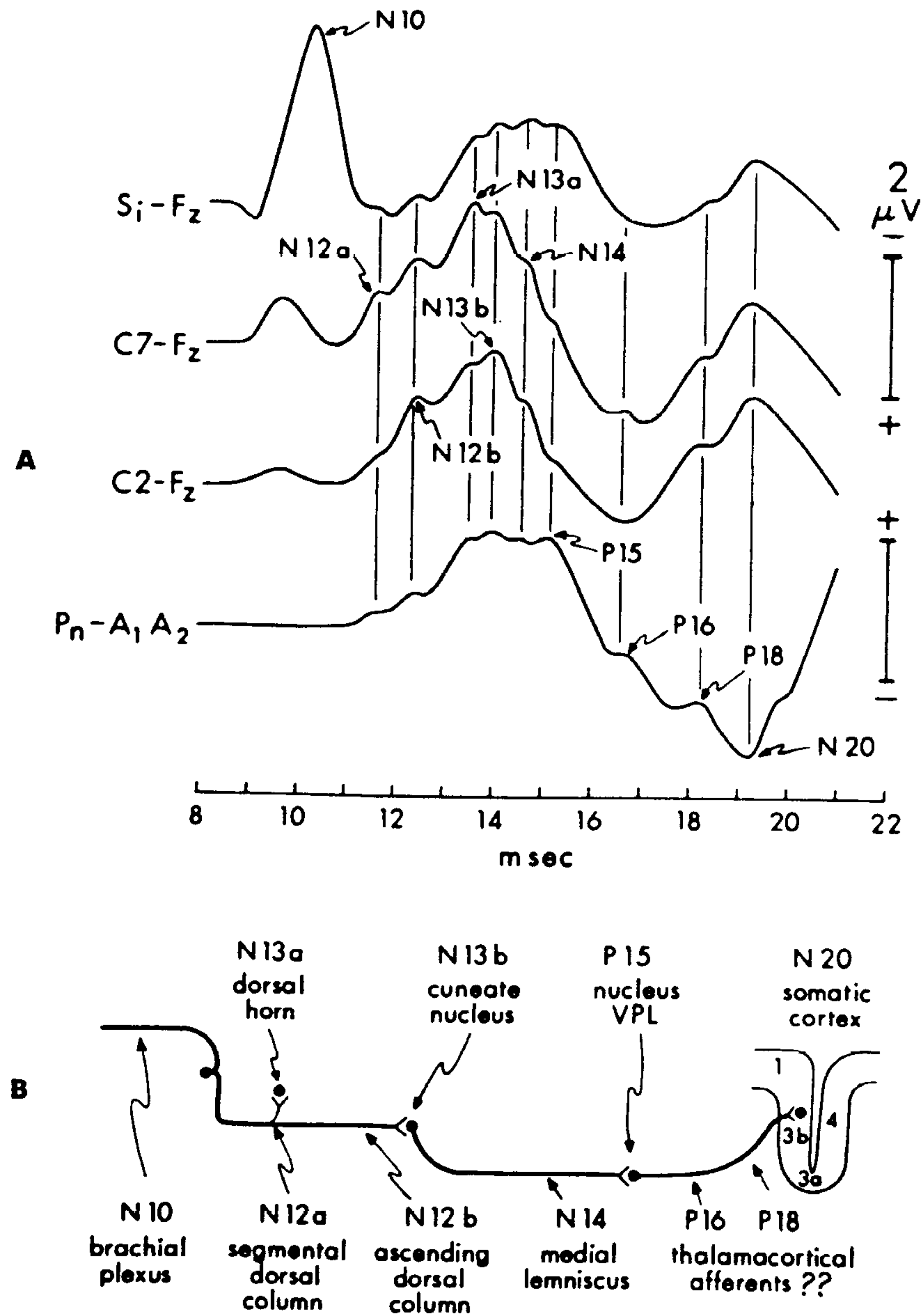
Temporal aspects of MEG & EEG

- Normal power spectrum of ongoing activity shows 1/f behaviour plus alpha band activity
- Changes in ongoing signals can be induced by sensory stimulation: ERF: Event Related Fields, ERP: Event Related Potentials
- ERF and ERP are significantly smaller than ongoing signals. Maximal SNR ~ 1:5; thus averaging necessary



Event-related potentials need averaging.

Each component in the waveform is thought to have a characteristic neural origin.

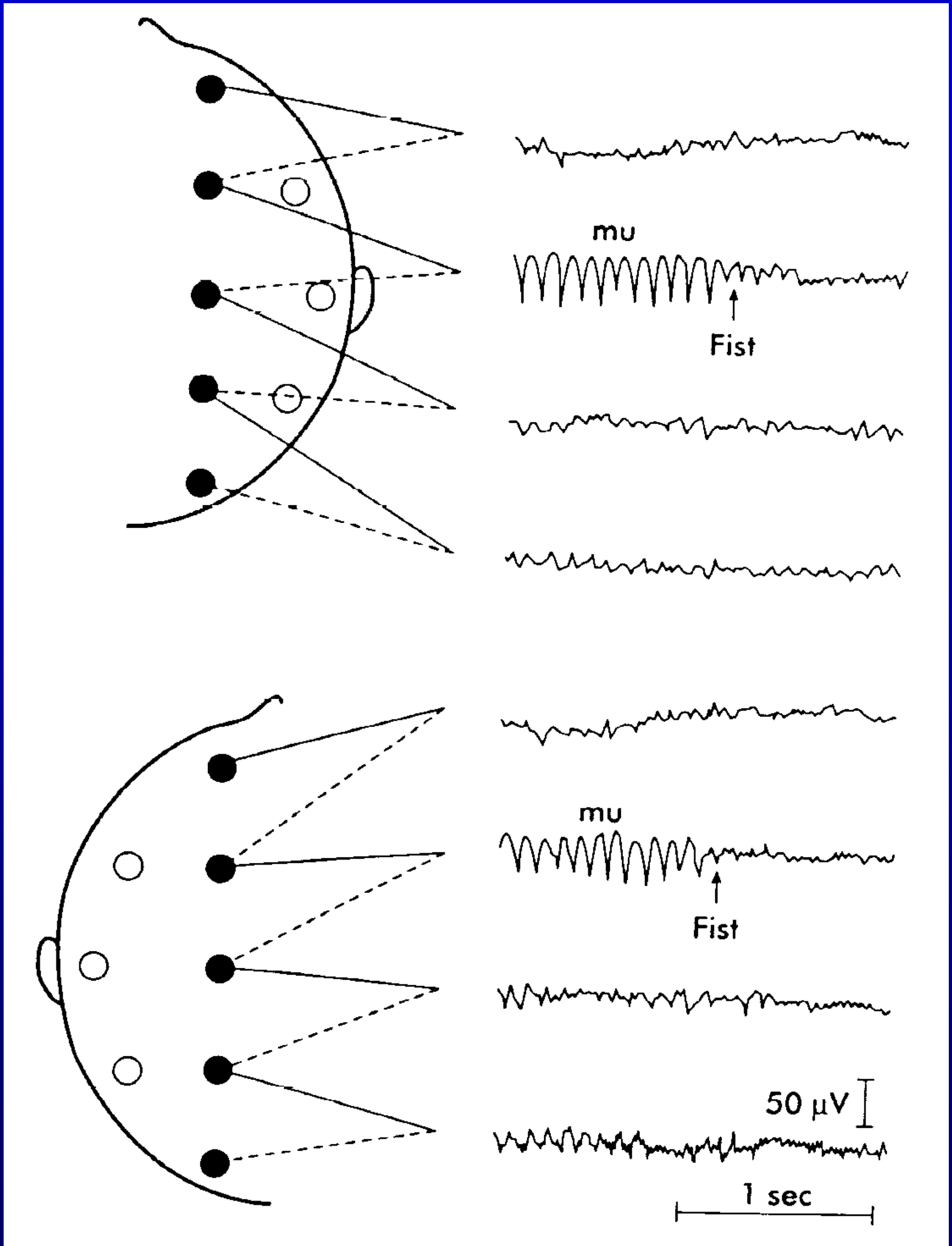


Oscillatory dynamics

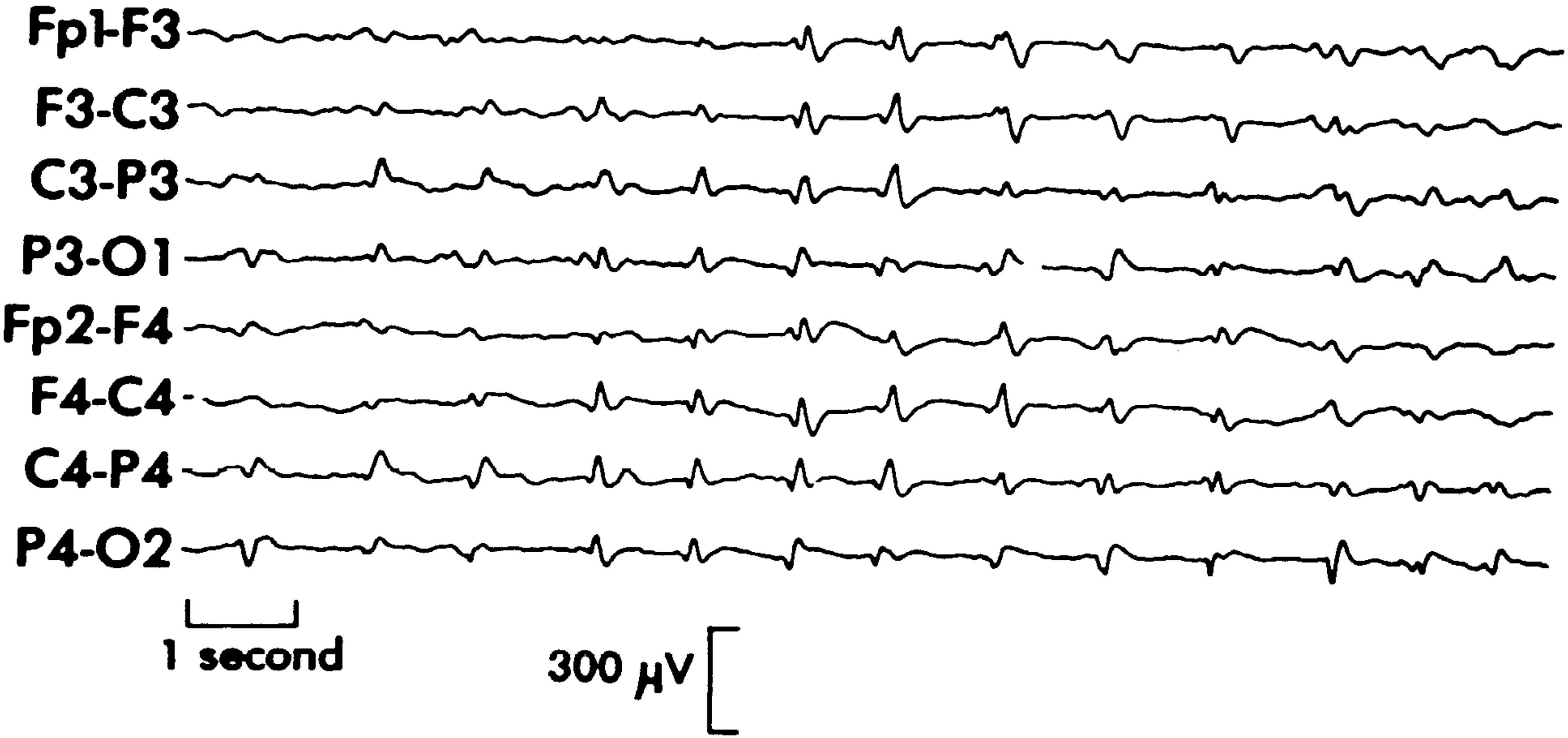
- Event related desynchronization of the alpha, mu and tau rhythms occurs upon events that require processing of many stimulus aspects or recall (Pfurtscheller, 89)
- Event related synchronization occurs in the gamma band upon similar “global” stimuli (Freeman, 76)
- Many pathological conditions are associated with increased ongoing, mostly slow, rhythmical activity
- During maturation oscillatory activity increases in frequency and decreases in amplitude
- Sleep stages are characterized by different rhythms

Oscillatory Rhythms in EEG/MEG

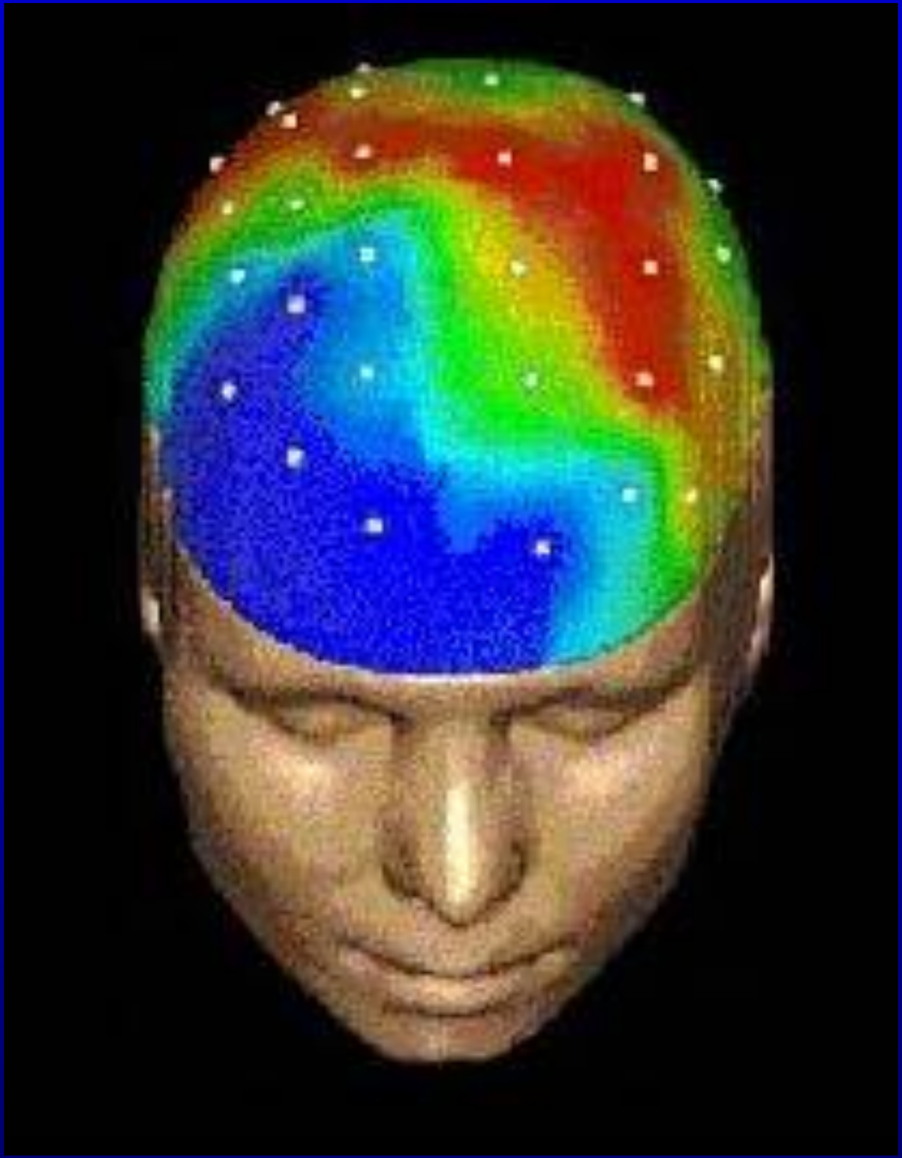
Alpha	EEG/MEG	8-13 Hz	Occipital
Beta	EEG/MEG	18-30 Hz	
Gamma	EEG/MEG	40+ Hz	
Delta	MEG/EEG	0-4 Hz	
Theta	EEG/MEG	4-8 Hz	
Mu	MEG/EEG	10-14 Hz	Central
Tau	MEG	12-16 Hz	Frontal

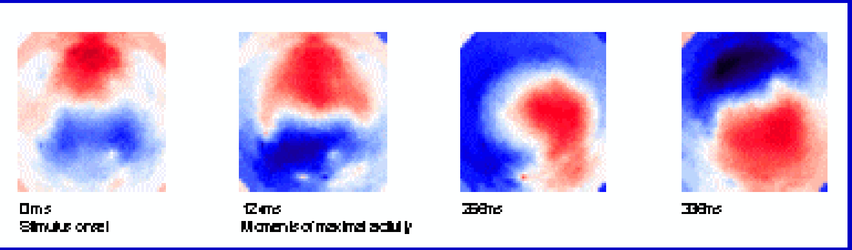


The mu rhythm is maximal in a central-frontal derivation. It is unreactive to eye opening and closing, but highly reactive to movements, such as making a fist.



Repetitive triphasic complexes are a characteristic finding in the EEG of patients with progressive Creutzman-Jacob disease.





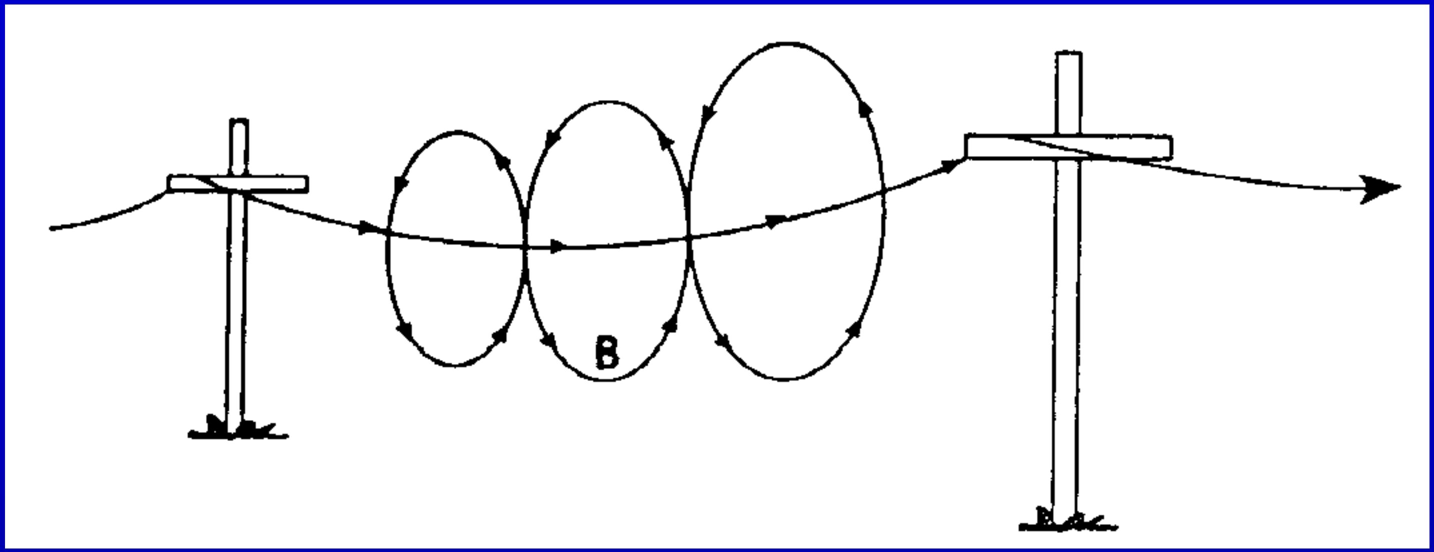
Brain topology mapping:
color coding of potential field

Introduction to MEG

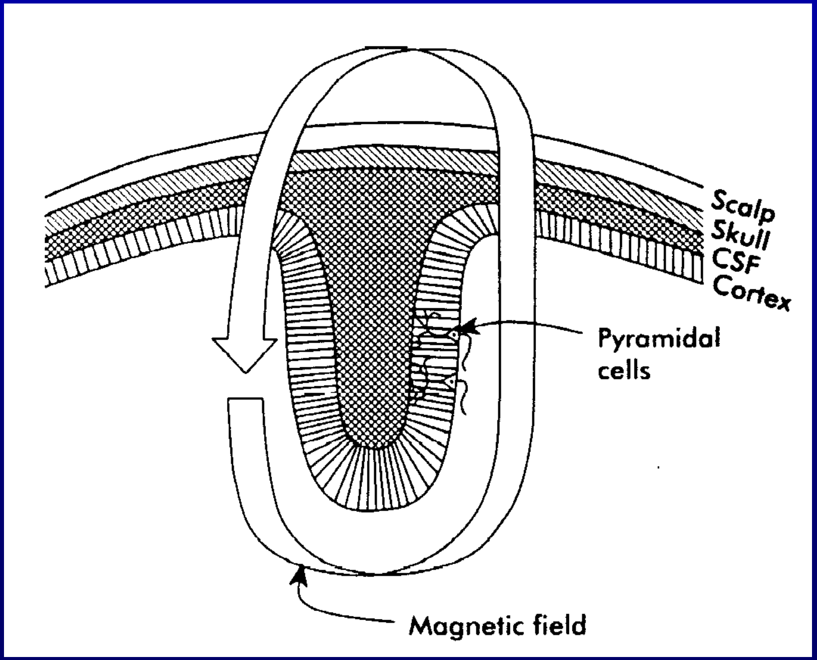
- MEG has better spatial resolution than EEG
- MEG is reference free
- MEG has much better temporal resolution than fMRI, PET or SPECT

but:

magnetic signals from the brain are <u>very</u> small and MEG systems therefore difficult and expensive

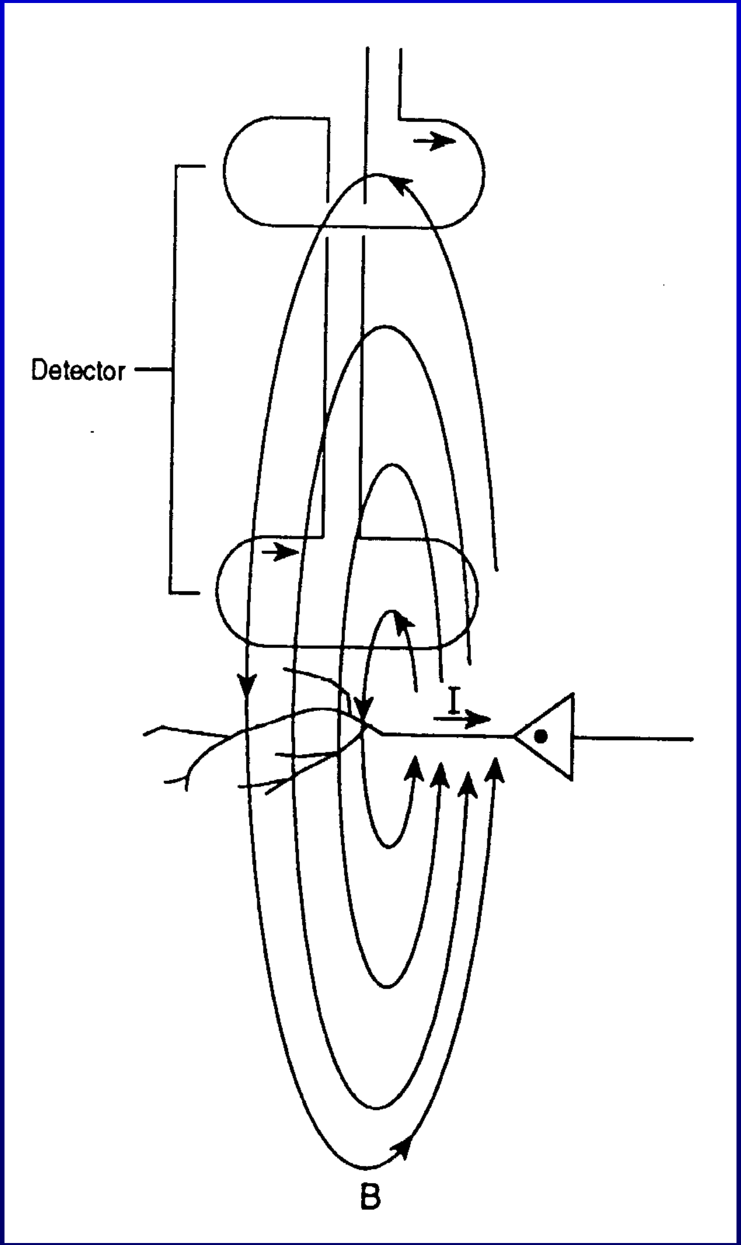


Every current induces a magnetic field



Time-varying neuromagnetic signals induce an electrical current in the wire loops of the detection coil.

For the axial gradiometer the upper and lower coil are wound in the opposite direction. The amount of current induced in the system therefore reflects the spatial gradient of the neuromagnetic field.



Signal Amplitudes of Biomagnetism and environmental

(in Tesla)

- 100 μT Earth Field
- 10μT
- 1μT
- 10-1000 nT Urban Noise
- 10 nT VW beagle at 50m
- 1 nT
- 100 pT screwdriver at 5m
- 10 pT
- 1 pT CMOS IC op 2m
- 100 fT diode op 1m
- 10 fT
- 1 fT noise-level Squids

- 1 nT lung particles
- 100 pT heart
- 50 pT muscle
- 20 pT foetal heart
- 10 pT MRG
- 1 pT alpha rhythm
- 20-100 fT Evoked Fields

Noise sources

- electromotors
- elevators
- power supplies
- cars
- trains
- MRI
- mechanical
- stimulus artefacts

metal implants
dental fillings
bra's
piercings
tattoos
hair dyes

- ECG
- respiration
- eye movements
- "ongoing brain signal"

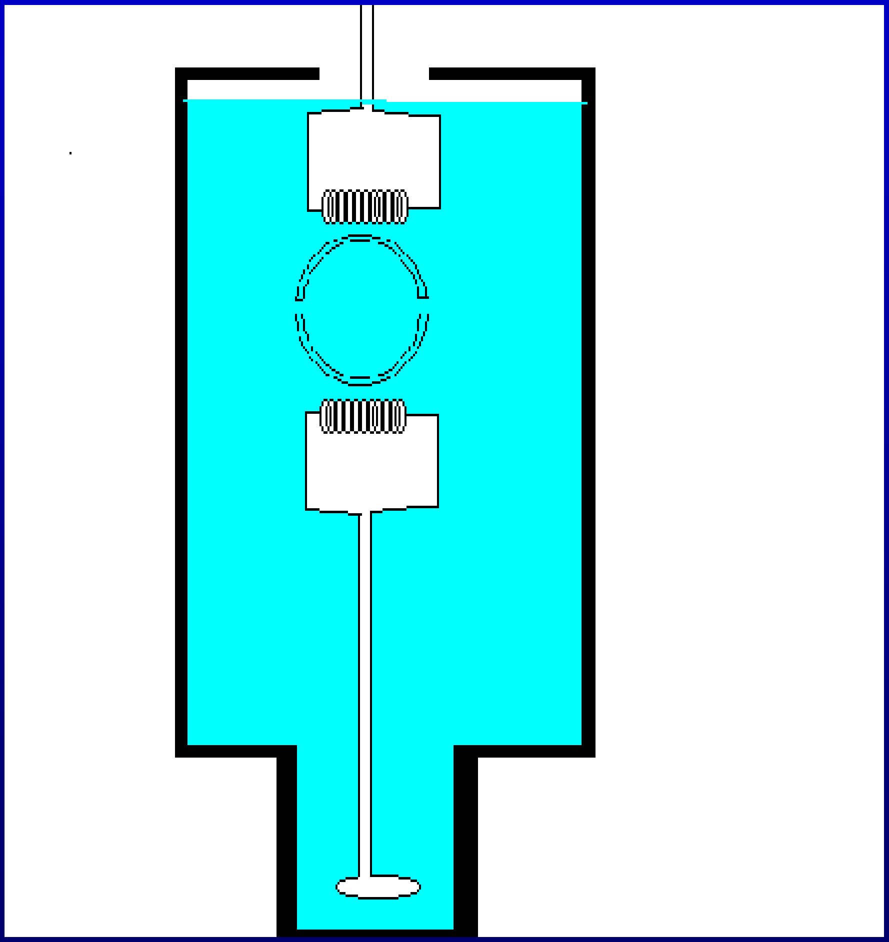
Noise elimination

- Shielding (MSR) 100.000x
- Gradient formation (hardware or software) 1000x
- Active compensation 0.1x-1000x
- Adaptive filtering 100x

Problems:

costs
introduction of high frequency noise
decreased sensitivity

How is the MEG recorded?



- changed flux through pick-up coil => current through input-coil
- induction => flux over SQUID
- Josephson junctions yield a potential
- This potential is cancelled by feedback current through the feedback coil
- The amplitude of the feedback signal is a measure of the flux at the pick-up coil.

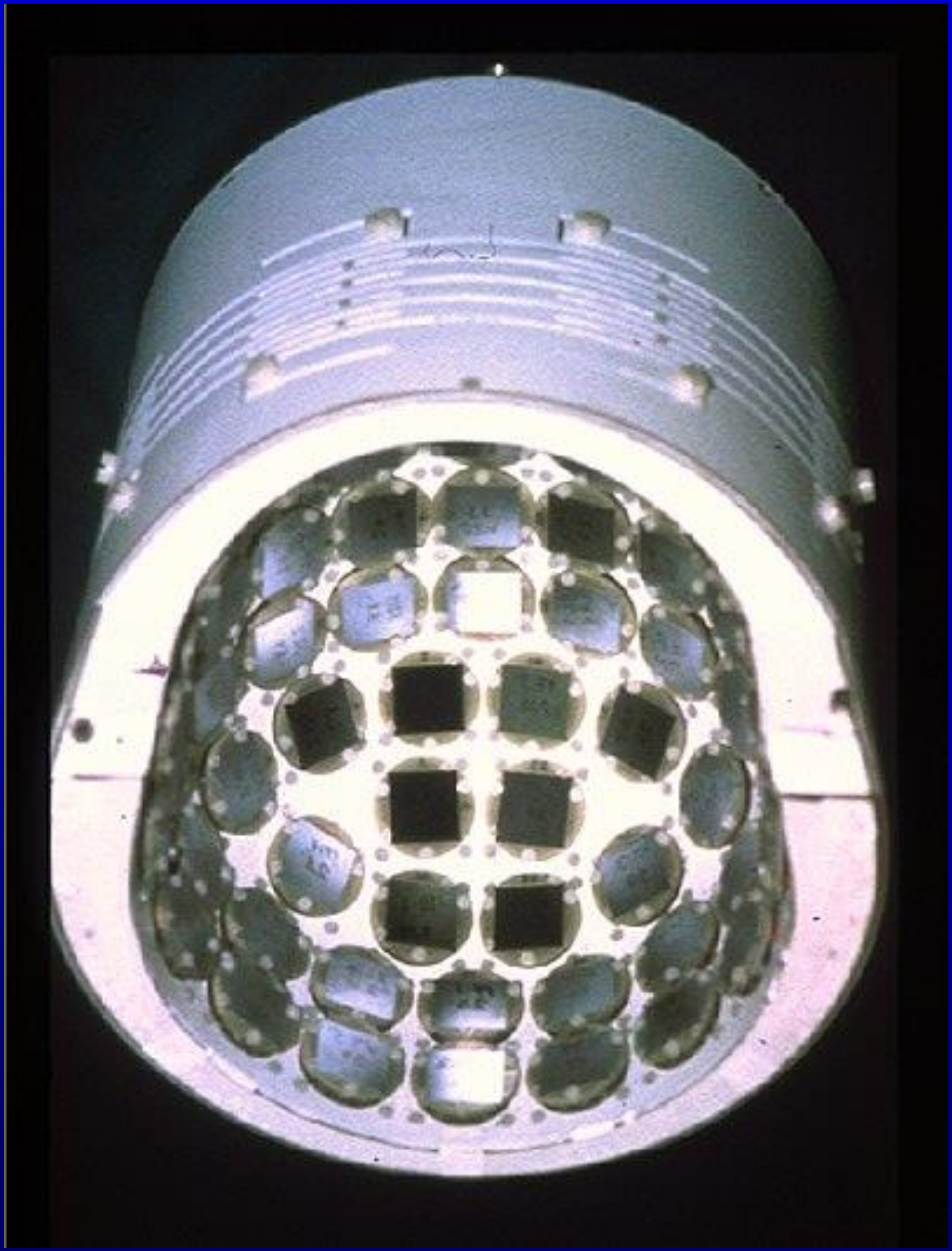
The 150 channel MEG system at the KNAW MEG/EEG Center at the Free University of Amsterdam (dr. B. van Dijk, director)

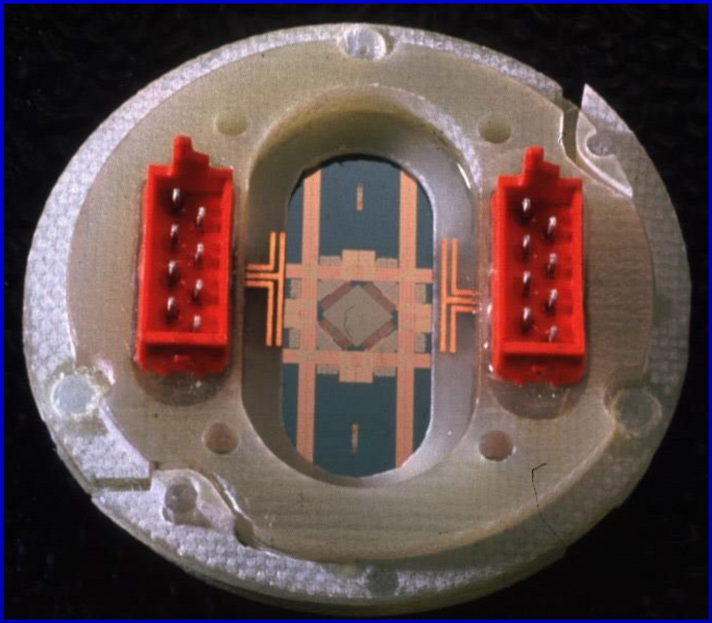
Present System Hardware

- 150 radial gradiometers; 5 cm baseline
- 29 field and gradient reference channels
- 72 EEG channels
- 16 ADC channels
- 32 digital channels (I/O)


CTF
SYSTEMS
INC.



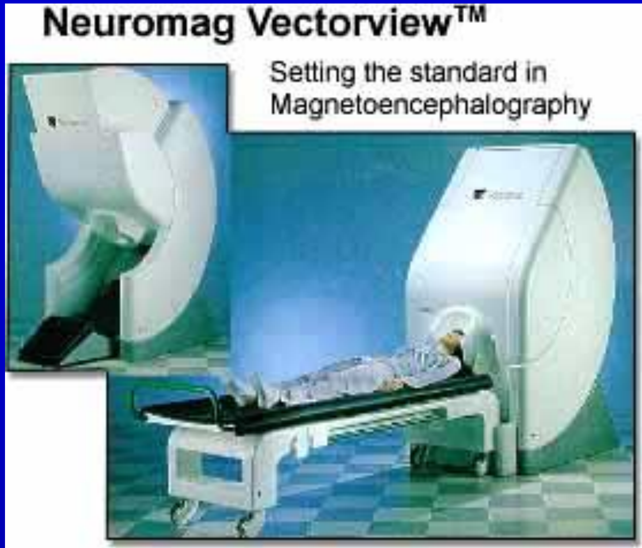



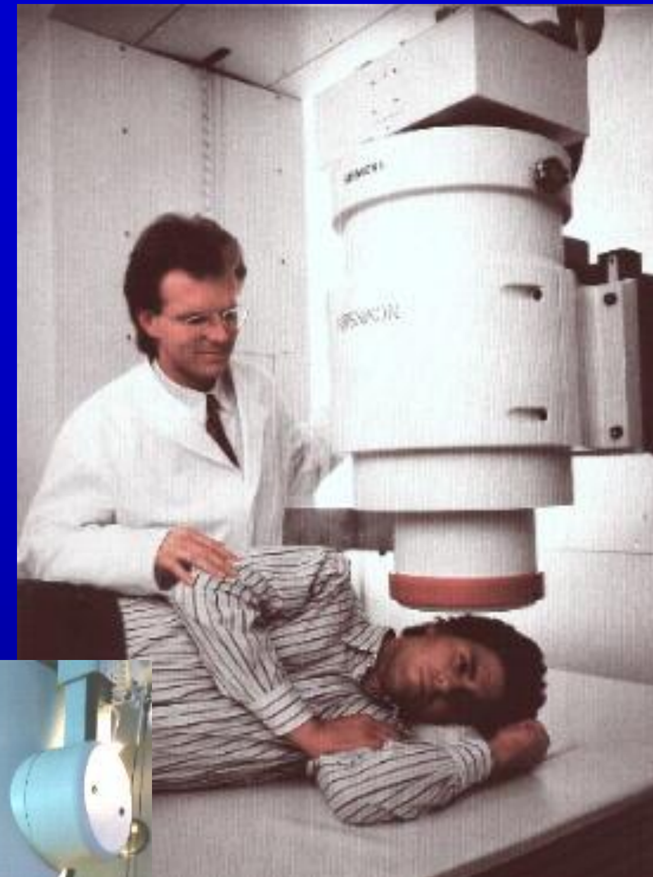


SQUID gradiometer

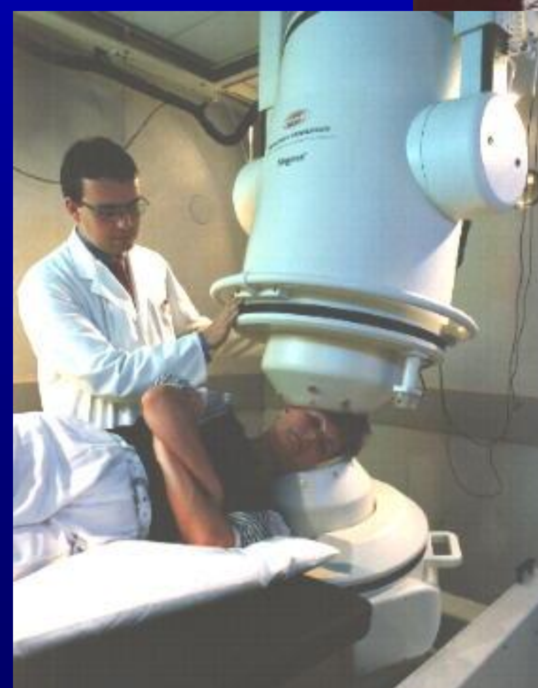
SQUID array

A Faraday shielding cage is necessary to prevent interferences with external Sources.


Neuromag Vectorview™
Setting the standard in
Magnetoencephalography




Neuromag




Neuromag


Neuromag

Analysis EEG & MEG

"Can we calculate the current sources in the brain from the measurements?"

- Forward solution
  - given the electrical current density
  - given the form, susceptibility and conductance of the different tissues of the head
- Calculate the magnetic induction or the electric field at the location of the sensors.

Analysis EEG & MEG

- Inverse solution:
  - given the magnetic induction/electric potential
  - assume a volume conductivity model
- calculate the electrical current density

Fysical basis EEG & MEG

- Macroscopic Maxwell equations (linear; relations between D,H,B,E,j,s)
- Material properties (conductivity, polarizability, susceptibility)
- Quasi static approximation (time derivatives can be neglected)
- Assume that material properties are homogeneous at the location of the sources

Fysical basis EEG & MEG

- Two decoupled expressions

  for the electrical potential:

$$\cdot \; \cdot \; j_i$$

and for the magnetic induction:

$$1 \quad 1 \; B \quad 1 \quad j_i$$

- There are both in the electrical as in the magnetic case sources that do NOT lead to a macroscopic field.

So there exist **no unique inverse solutions**.

Analysis of EEG & MEG

- "SILENT SOURCES": Many electric current density distributions yield a magnetic induction field or a potential field that is identically zero outside the scalp.
- As a result the inverse problem is only solvable by making assumptions about both volume conductor and electric current sources

Volume conductors

Analytic

- infinite medium
- sphere
- sphere shells
- revolution ellipsoïds, with shells

Numerical

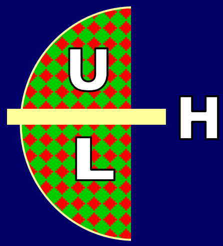
- "realistic" models
  boundary elements
  finite elements

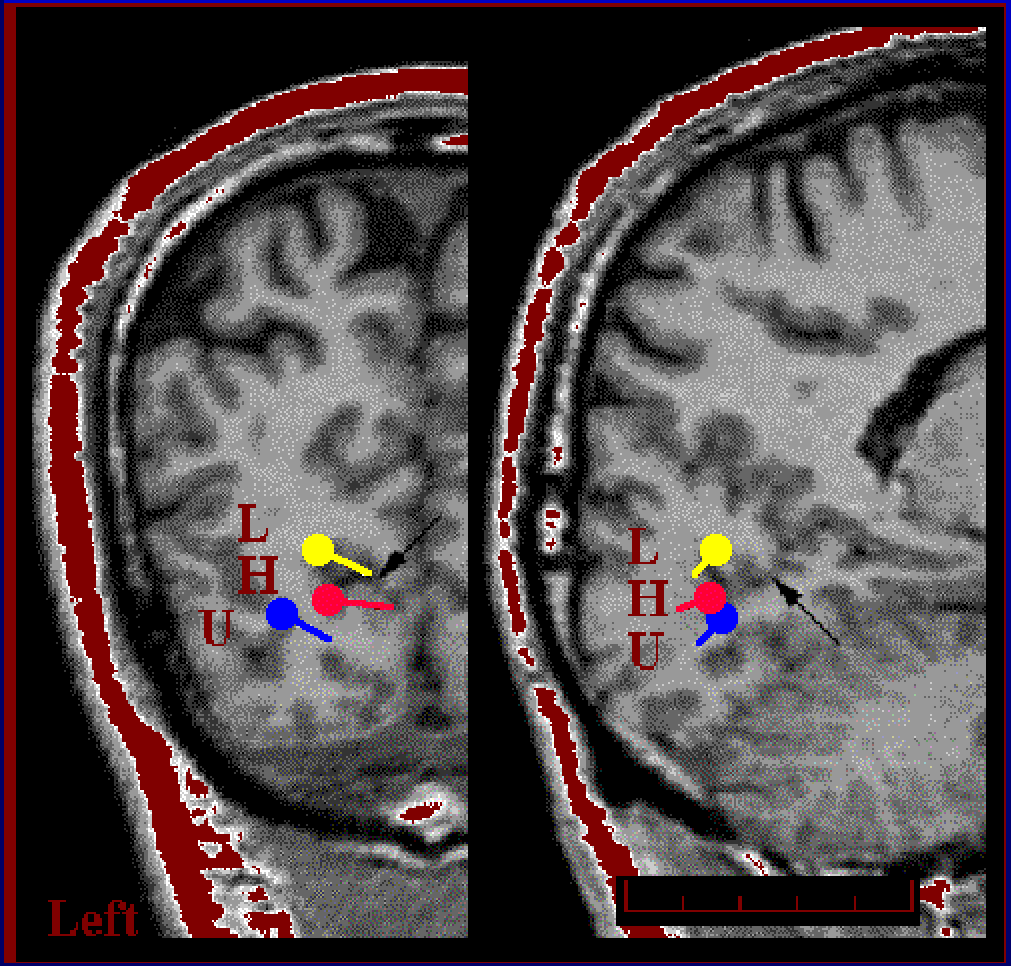
MRI or other head-form description necessary

stationary dipole co-registered to MR

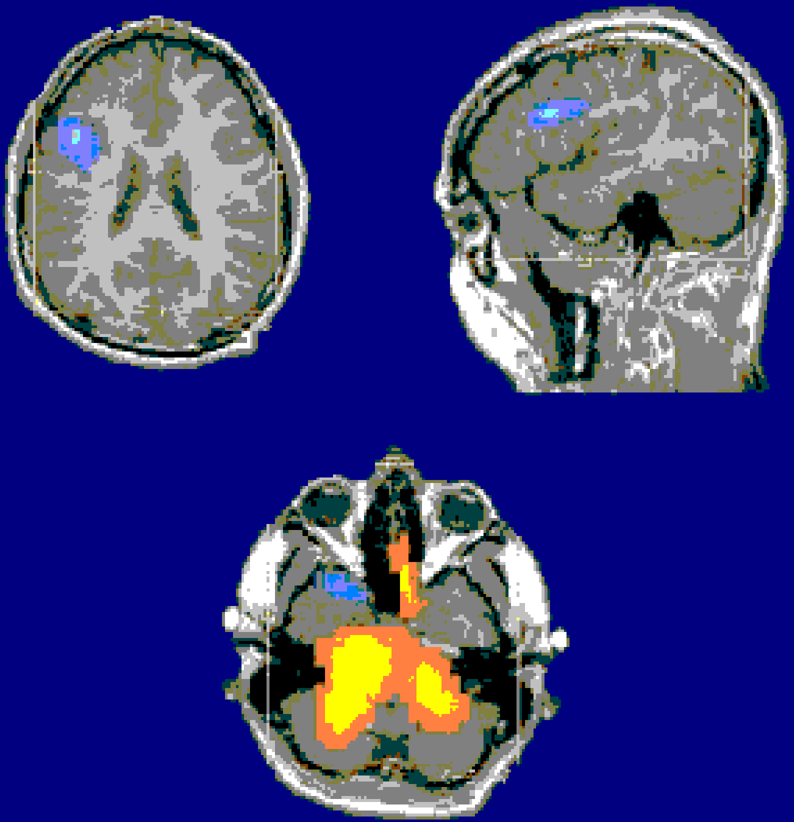
Visual
colour reversal

L: Rt Lower 1/4
H: Rt Half
U: Rt Upper 1/4

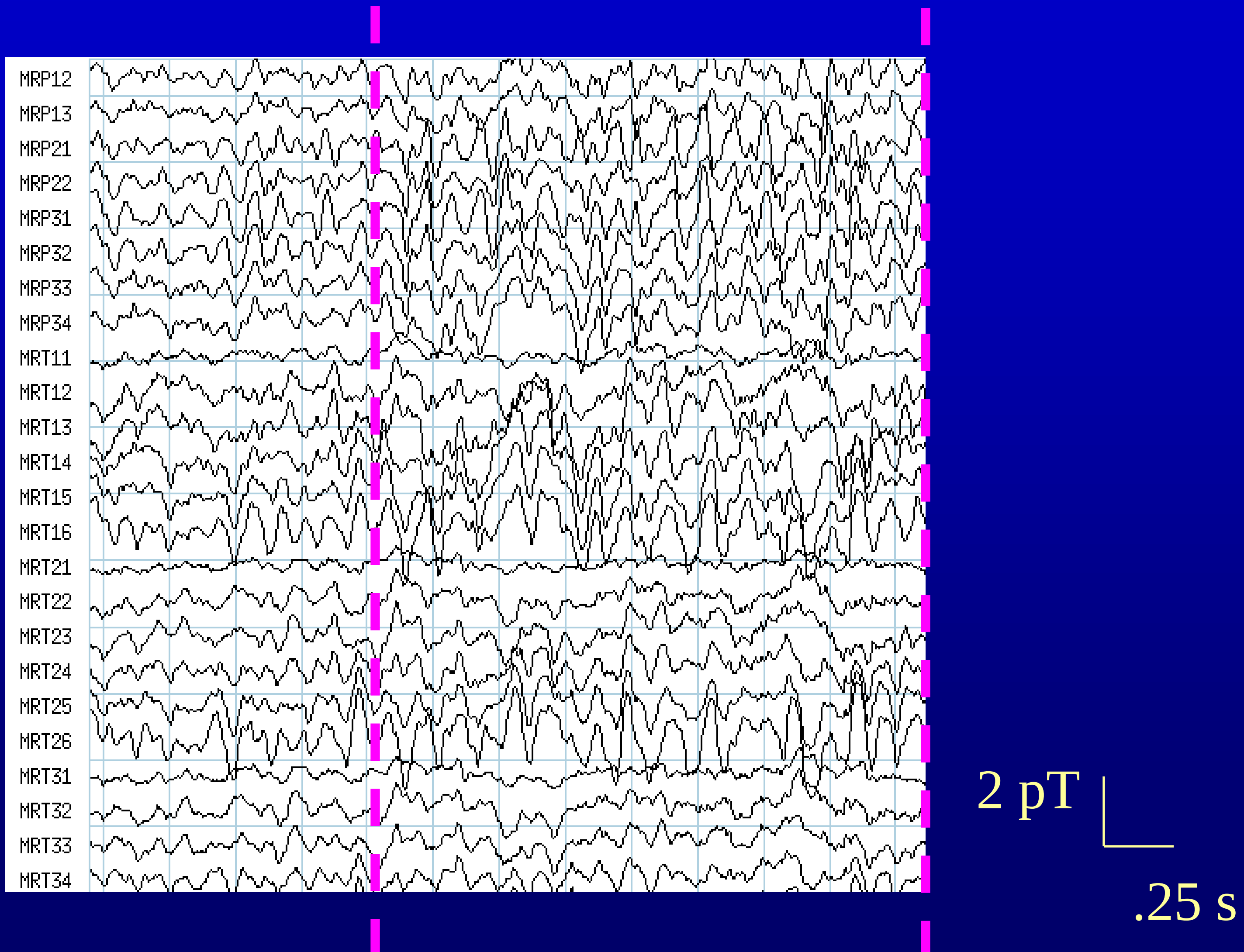


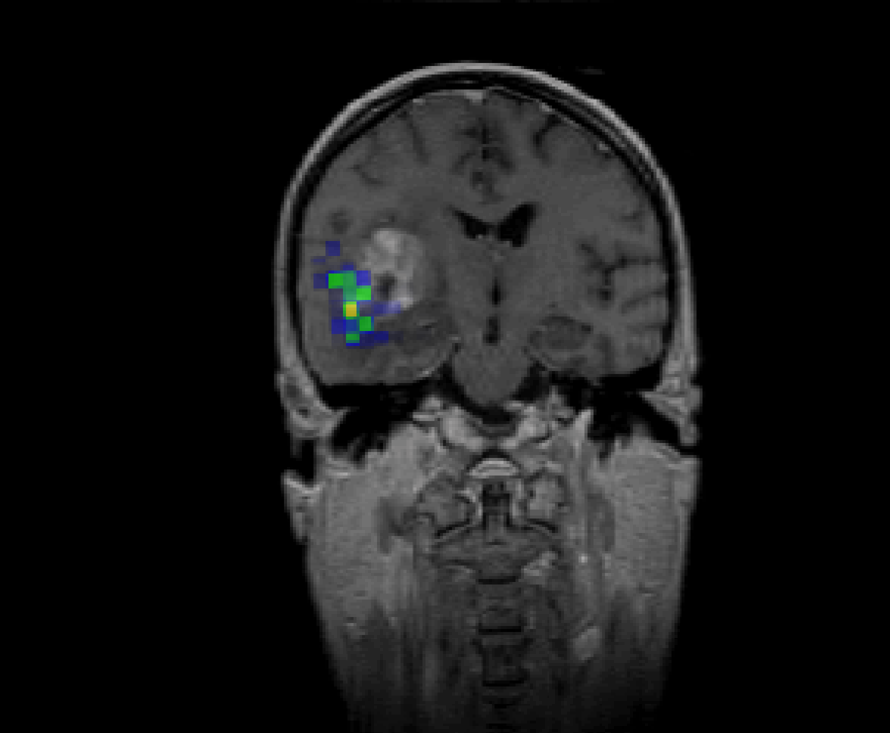


Picture Naming vs. Picture Recognition

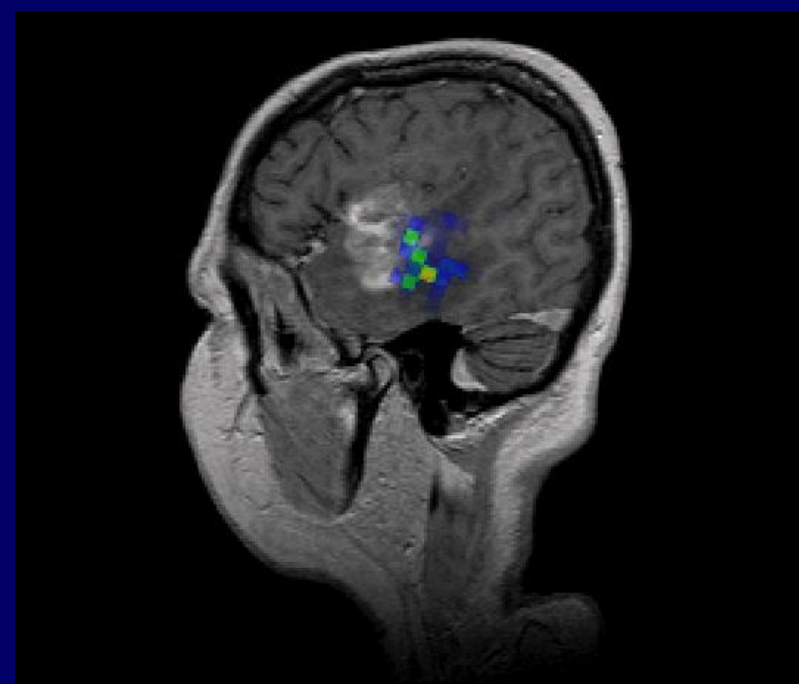


AbnormalLowFrequencyMagneticActivity

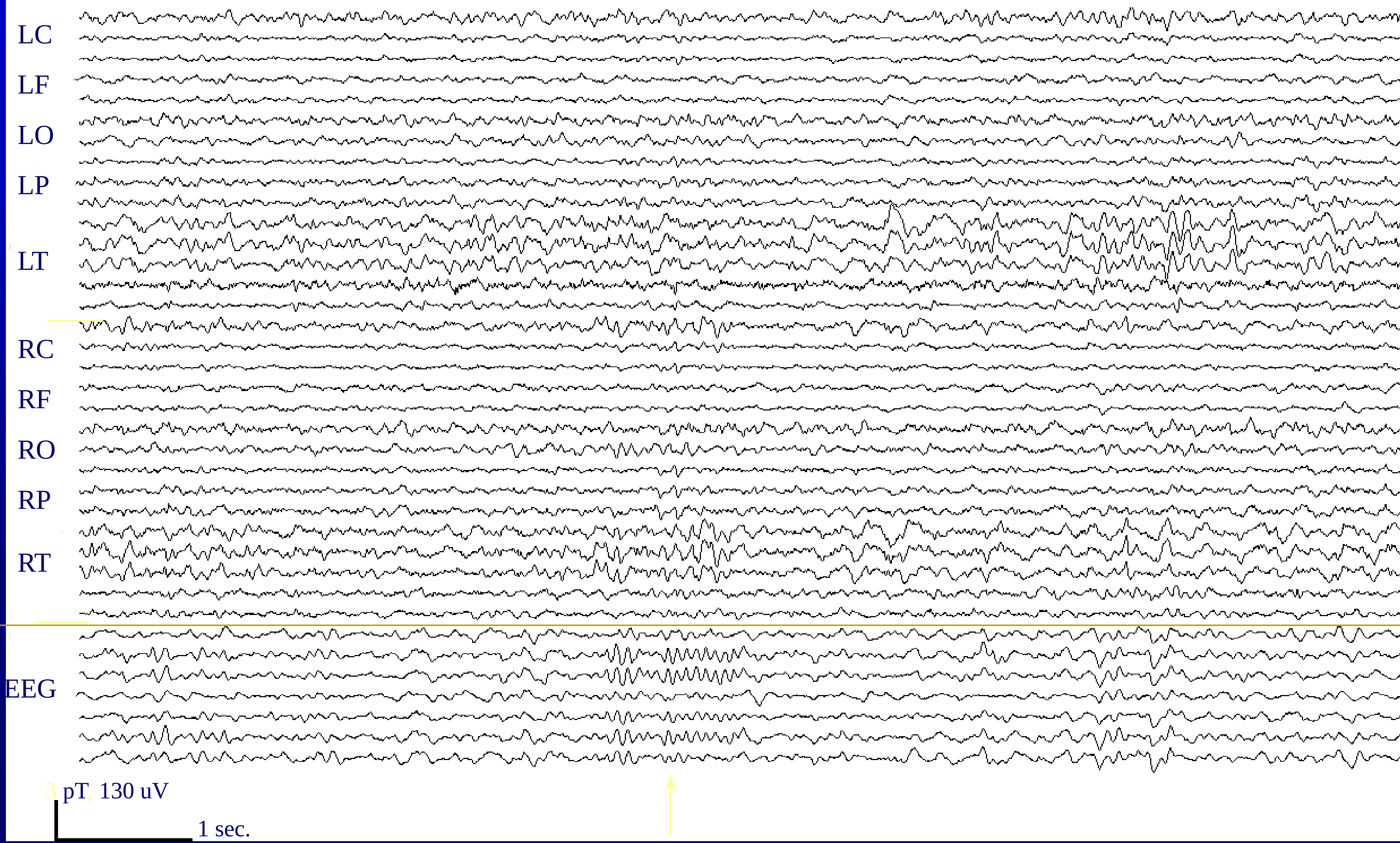




ALFMA



Sleep spindles EEG and MEG



Sleep spindles