

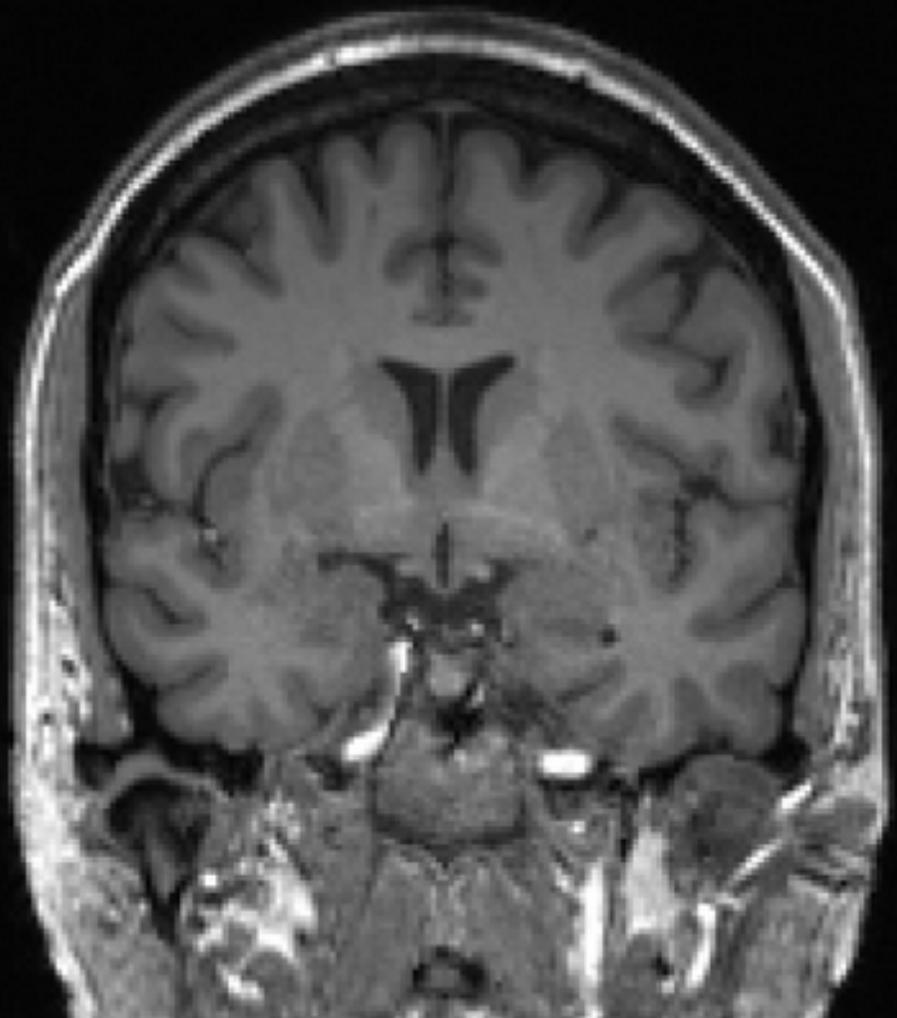
Health Informatics
Foundations of Science

Why Natural Sciences? Diagnostic Windows to the Brain

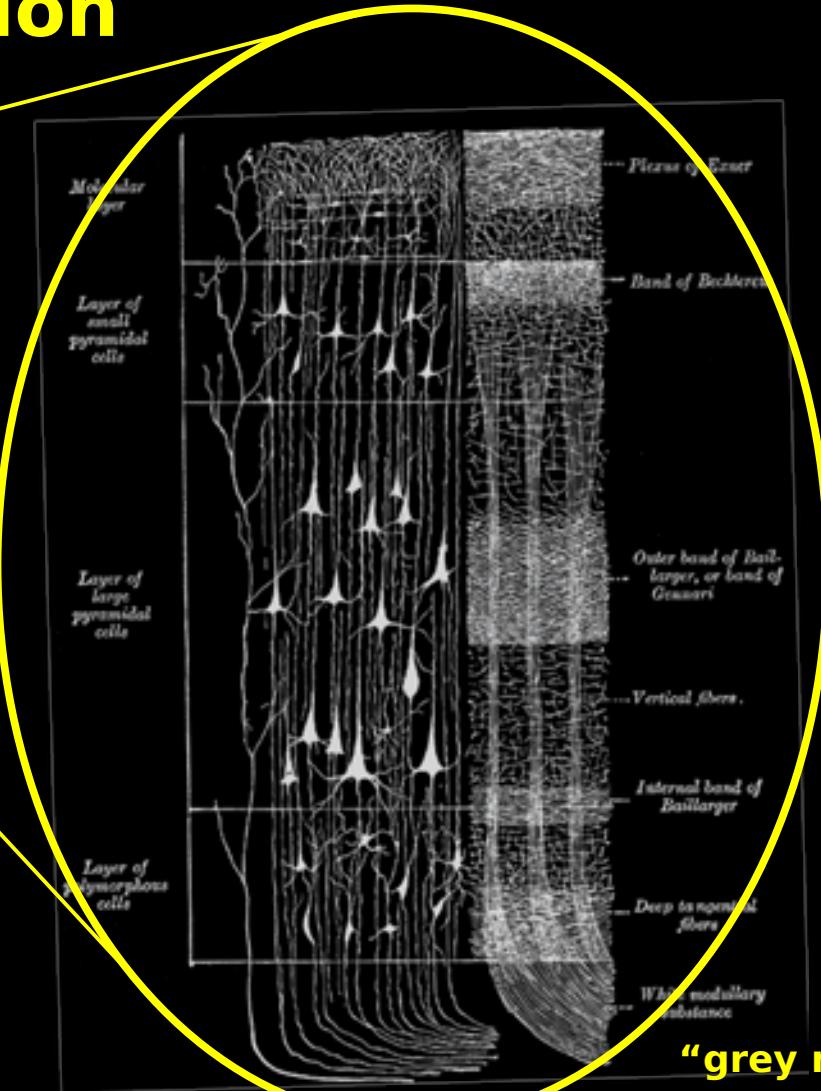
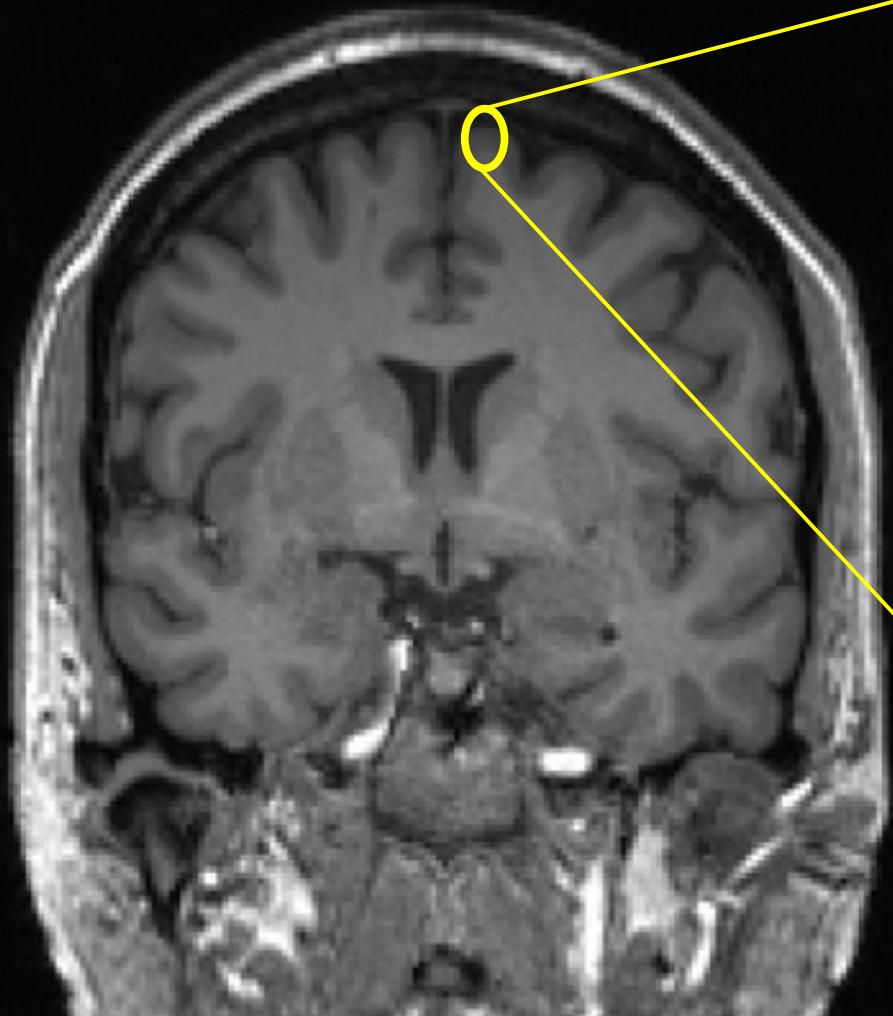
Christian Rummel

Support Center for Advanced Neuroimaging
Institute of Diagnostic and Interventional Neuroradiology
Inselgruppe AG, Bern

Brain Anatomy and Function

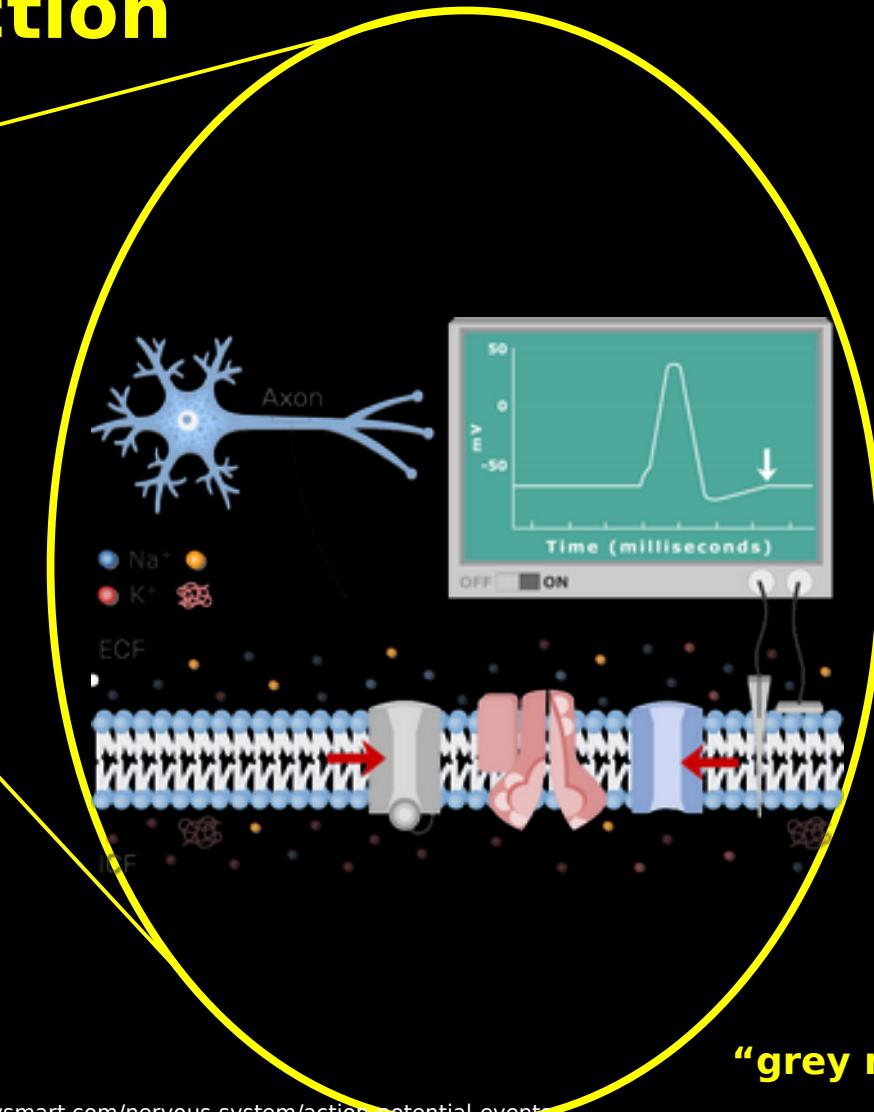
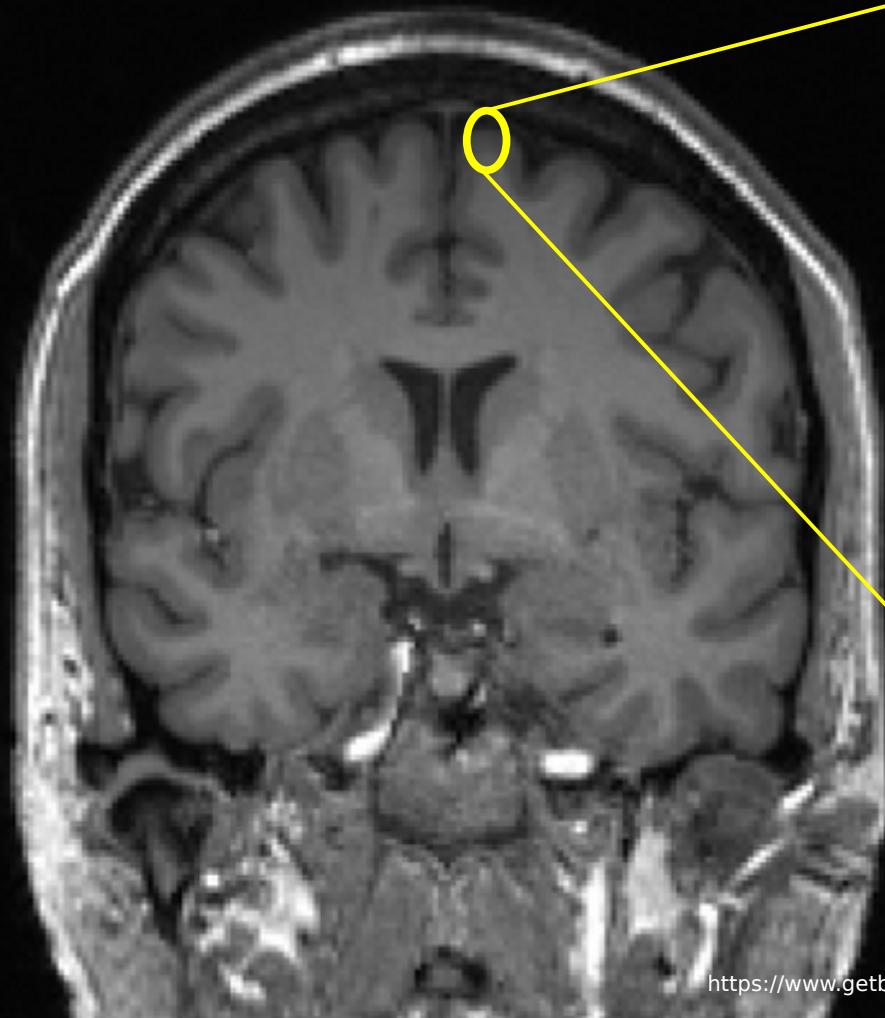


Brain Anatomy and Function

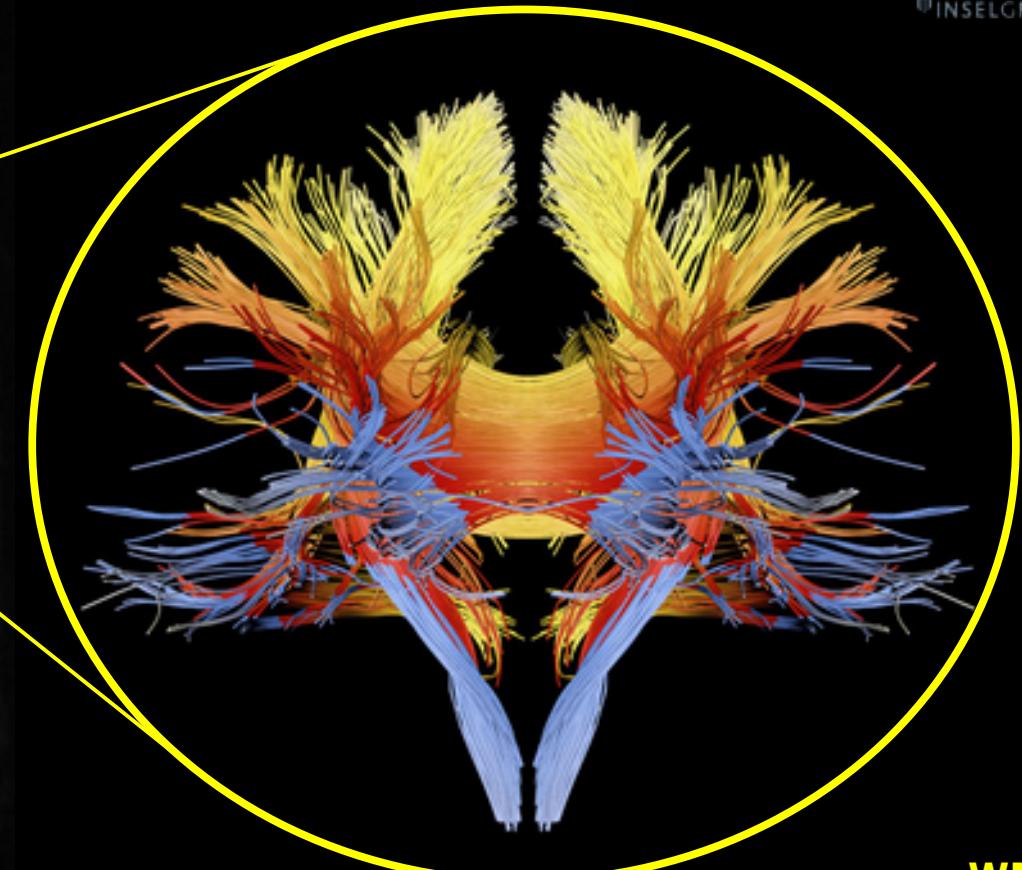
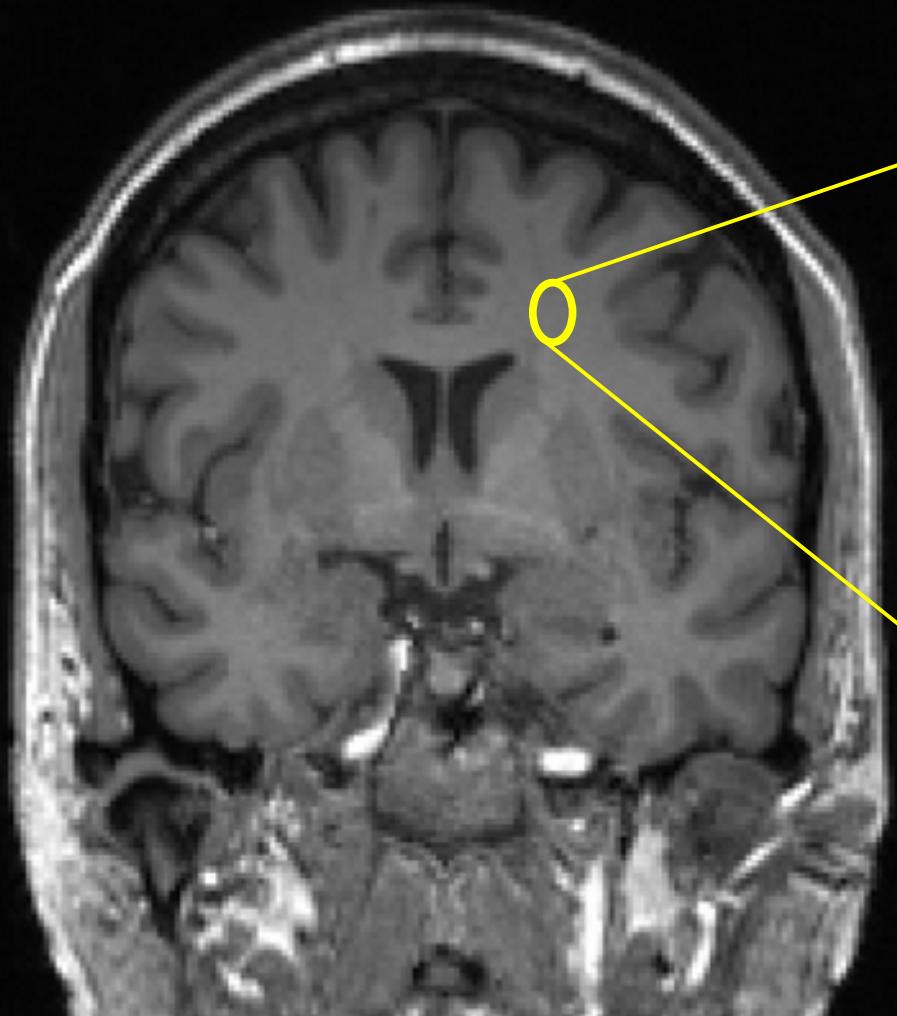


GM:
“grey matter”
neurons

Brain Anatomy and Function

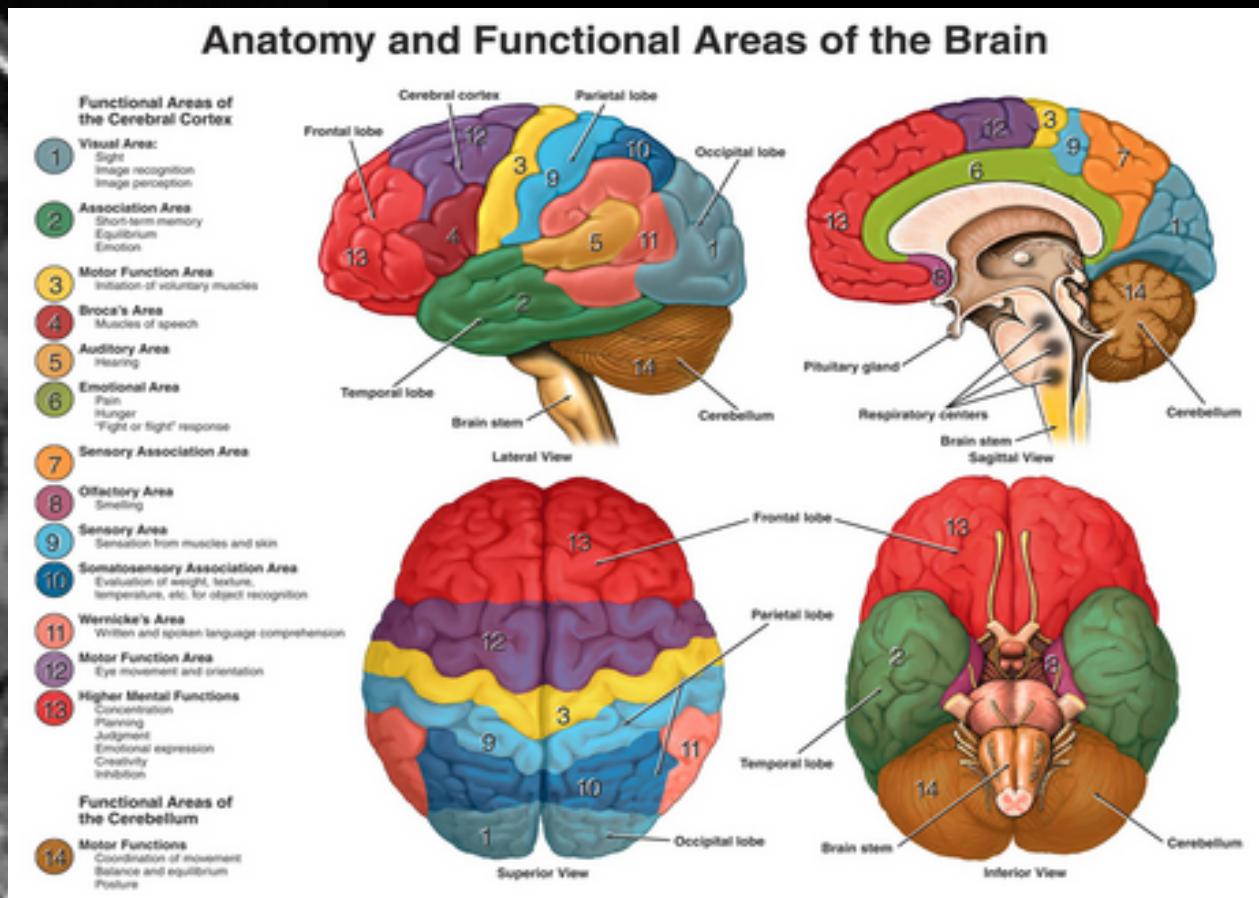
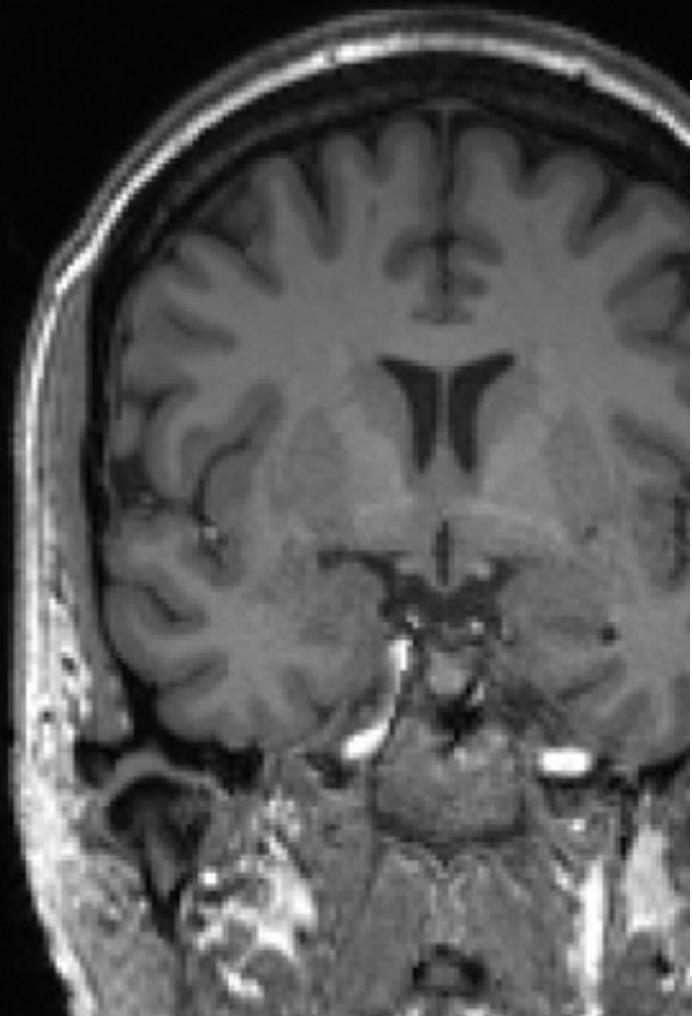


Brain Anatomy and Function



WM:
“white matter”
fiber connections

Brain Anatomy and Function

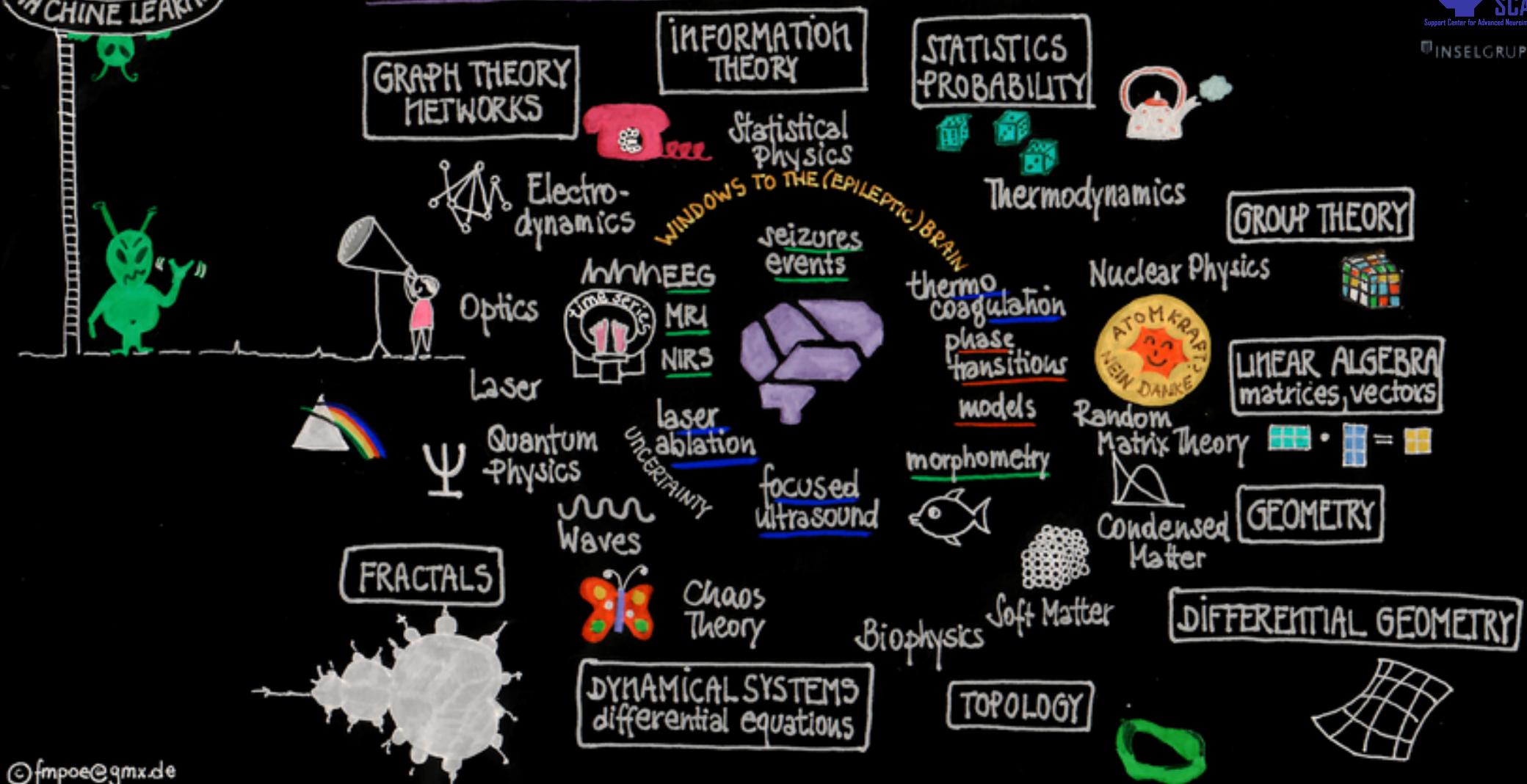


Diagnostic Windows to the Brain

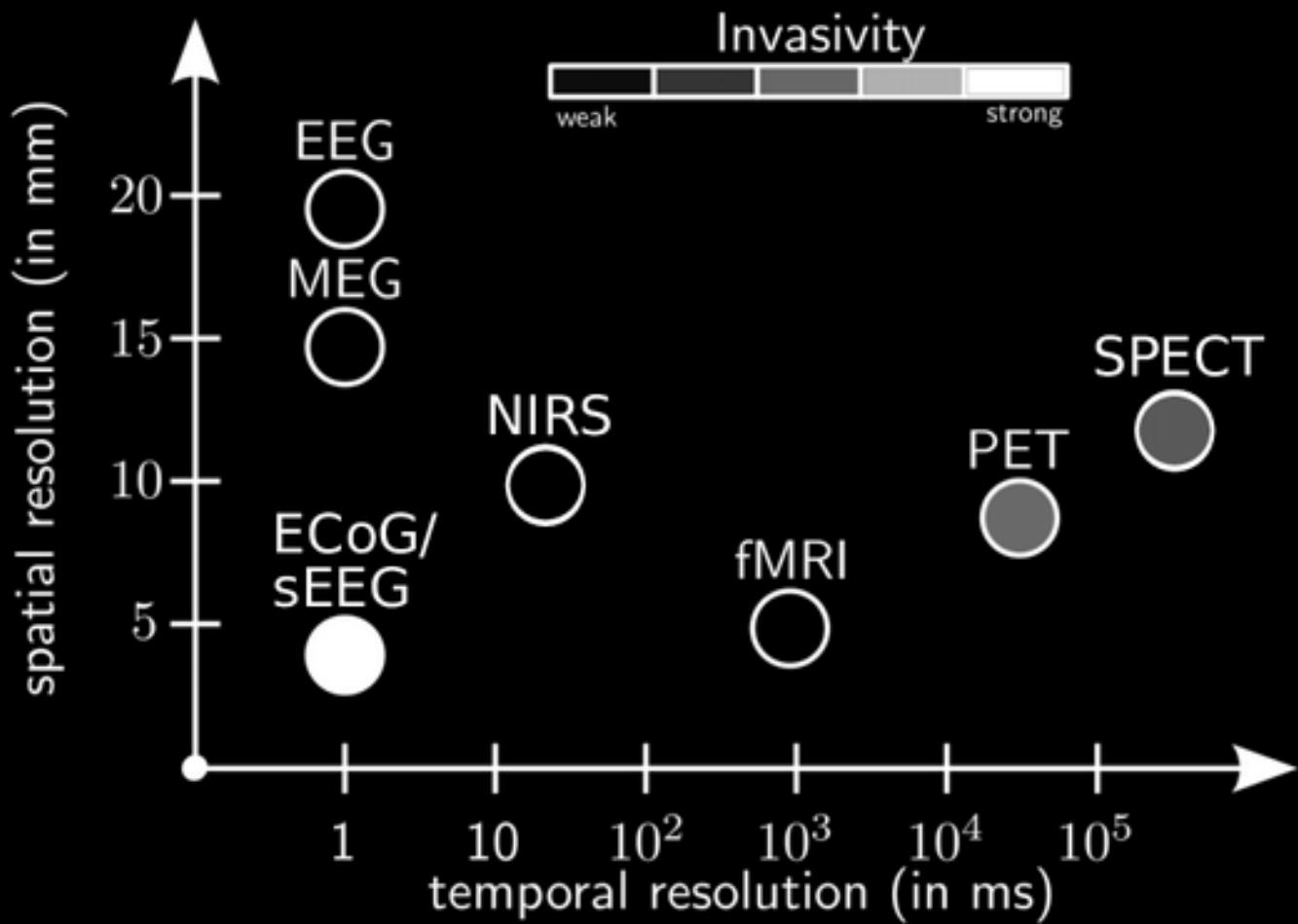




PHYSICS (& MATHS) of EPILEPSY RESEARCH



Diagnostic Windows to the Brain

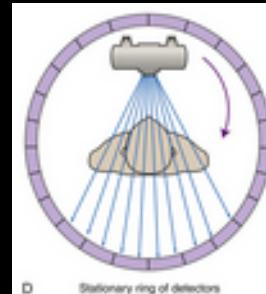
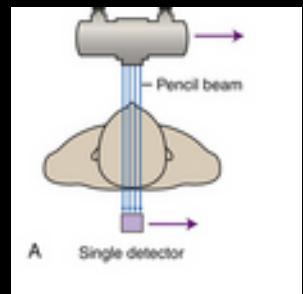
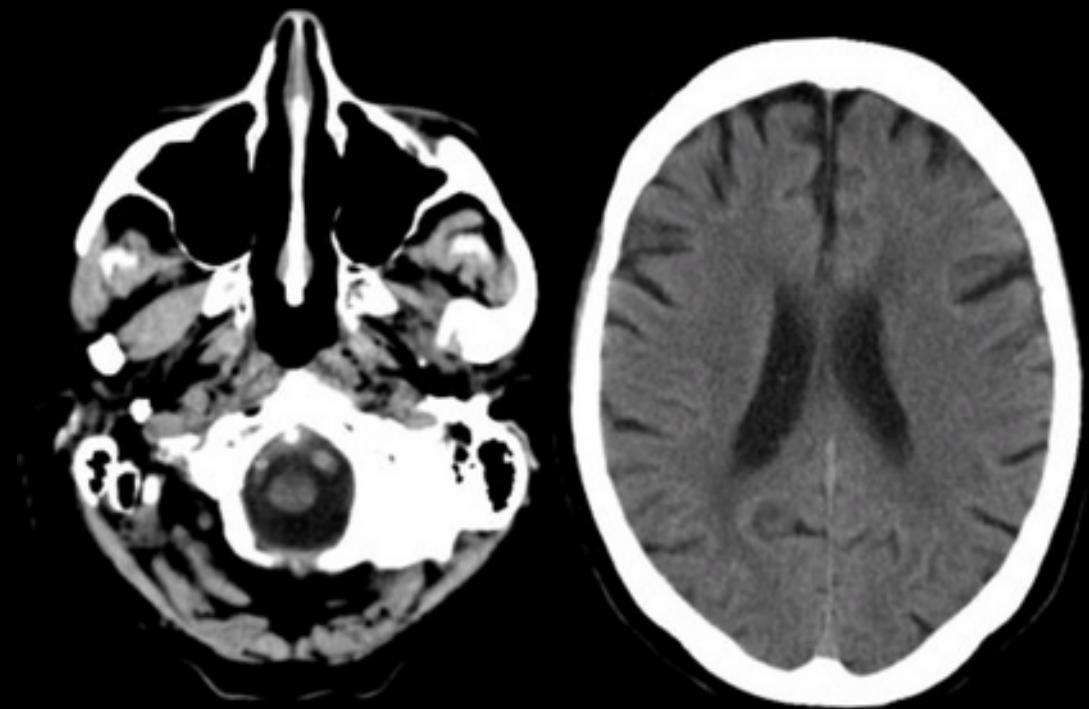


Computed Tomography (CT)

Rotating X-Rays

3D object → 2D projection image





Rotating X-Rays

Algebraic Reconstruction Technique (ART)

known:

X-ray intensities
measured by detector

wanted:

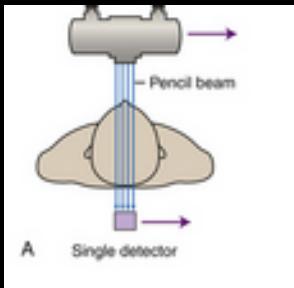
pixel opacities
/ densities

known:

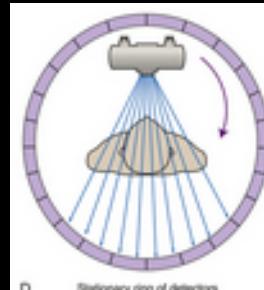
properties of CT scanner
(sparse) “design matrix”

$$1 * \#rays = 1 * \#pixels * \text{ }$$

#pixels * #rays

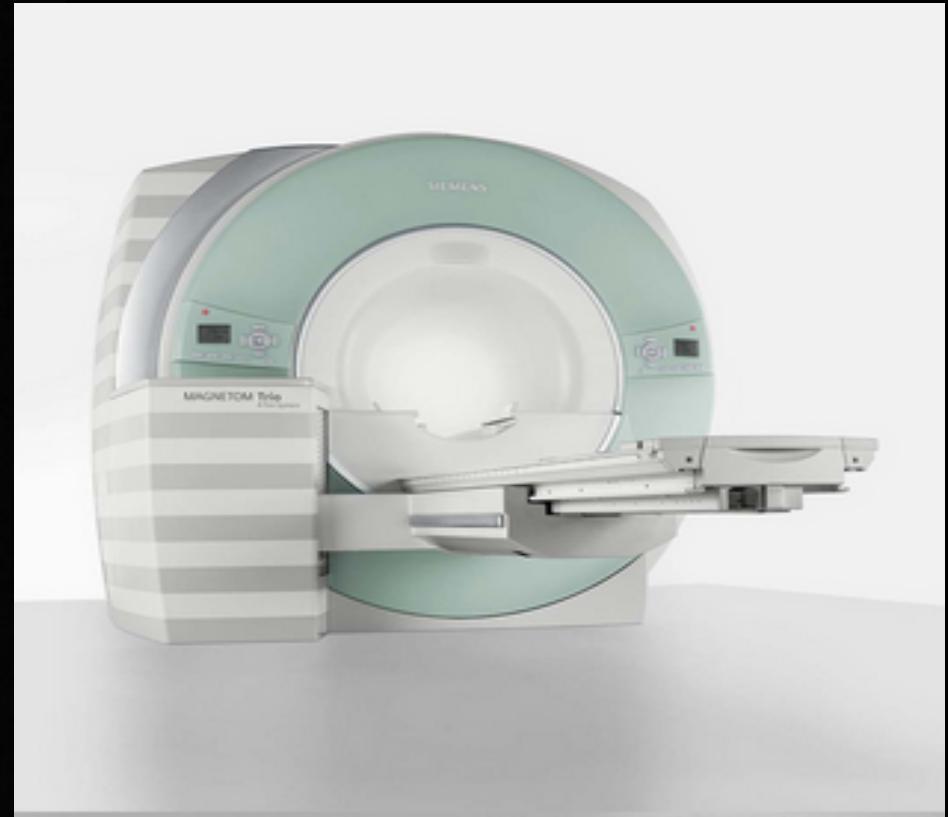
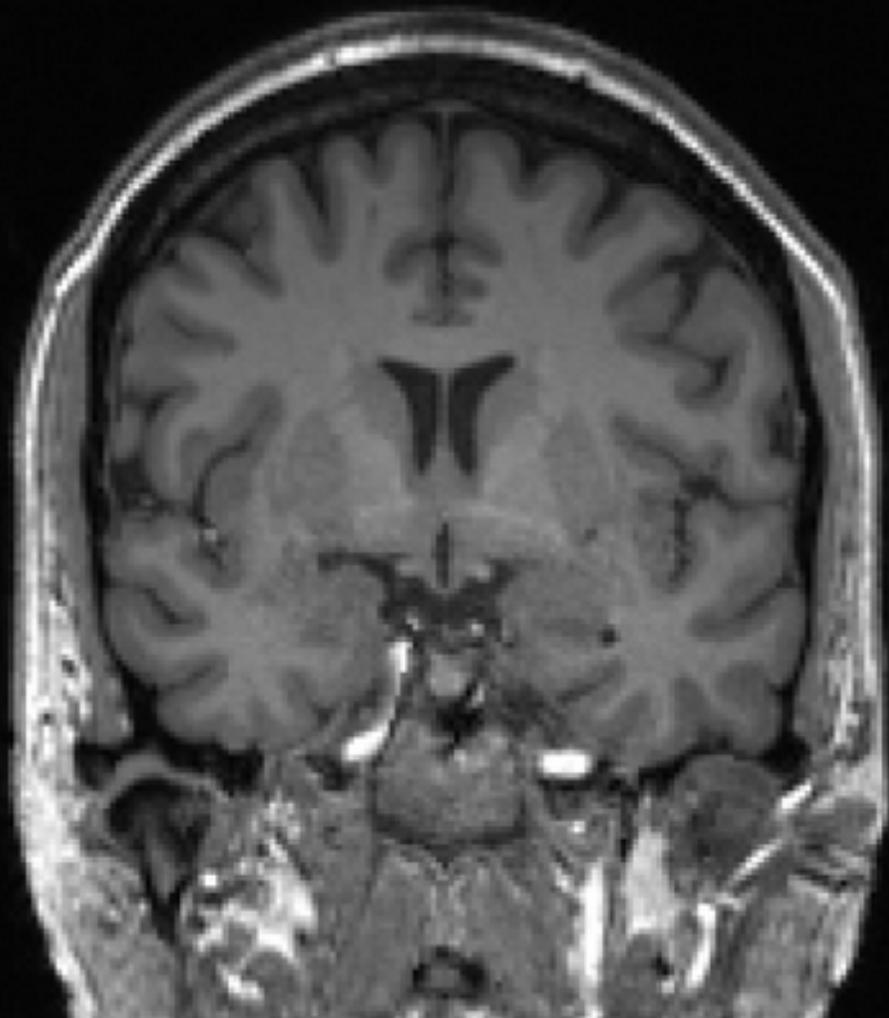


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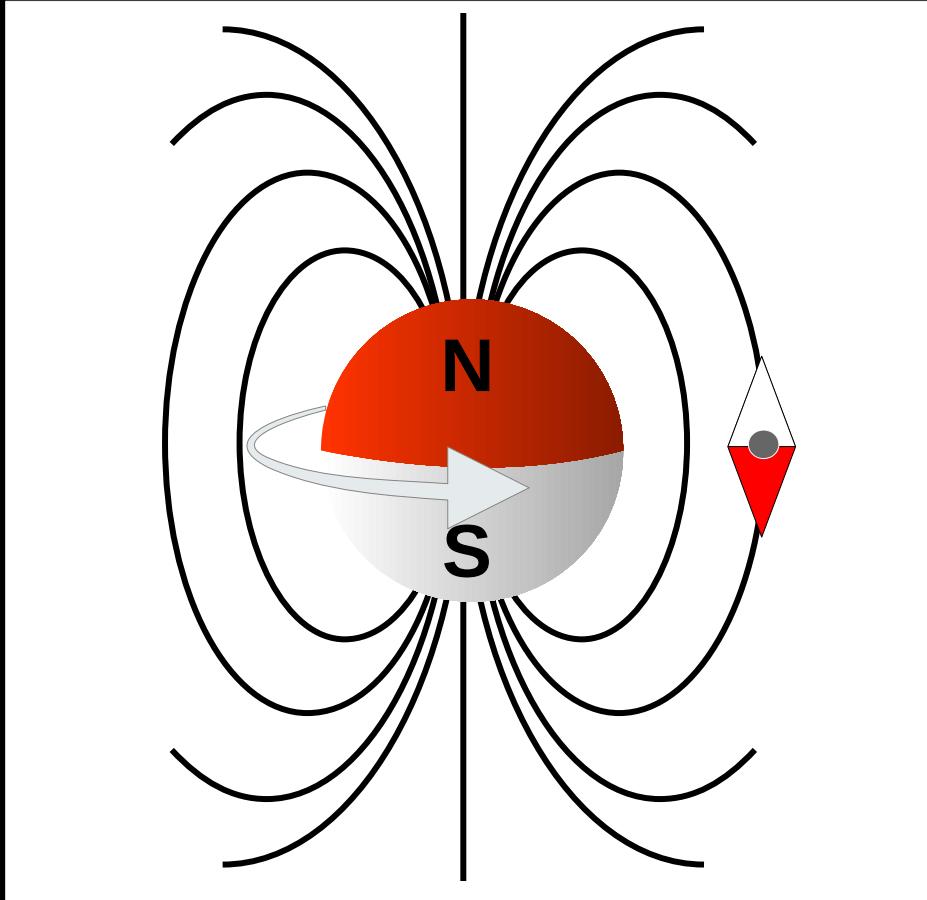


Magnetic Resonance Imaging (MRI)

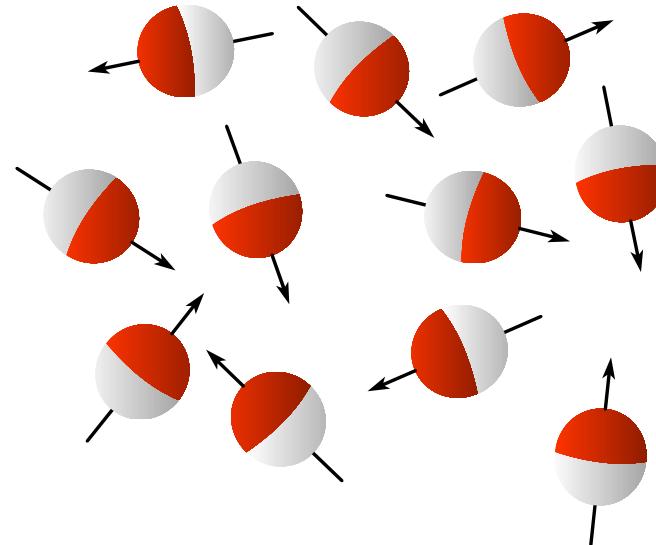
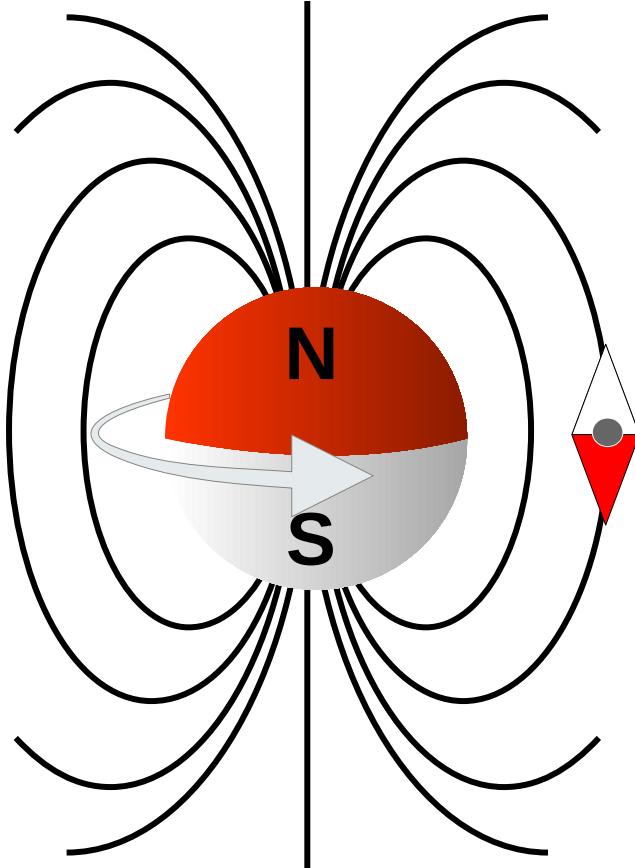
Proton Spins inside Magnetic Field



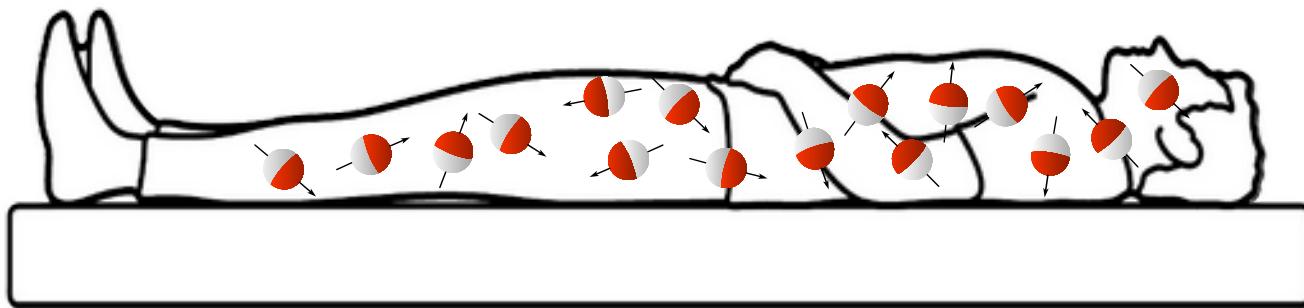
Proton Spins inside Magnetic Field



Proton Spins inside Magnetic Field



Proton Spins inside Magnetic Field



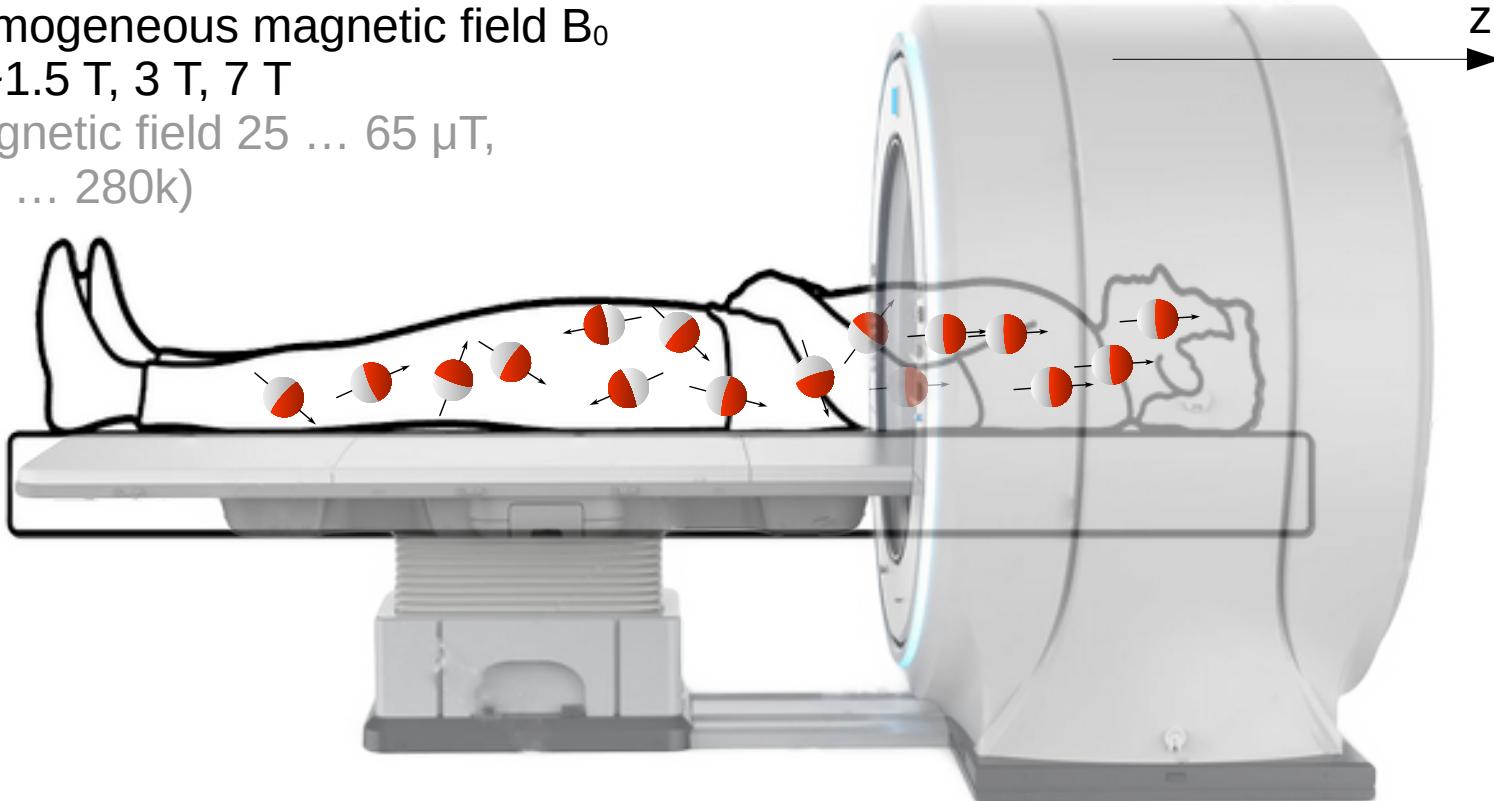
Proton Spins inside Magnetic Field

MR scanner:

strong homogeneous magnetic field B_0

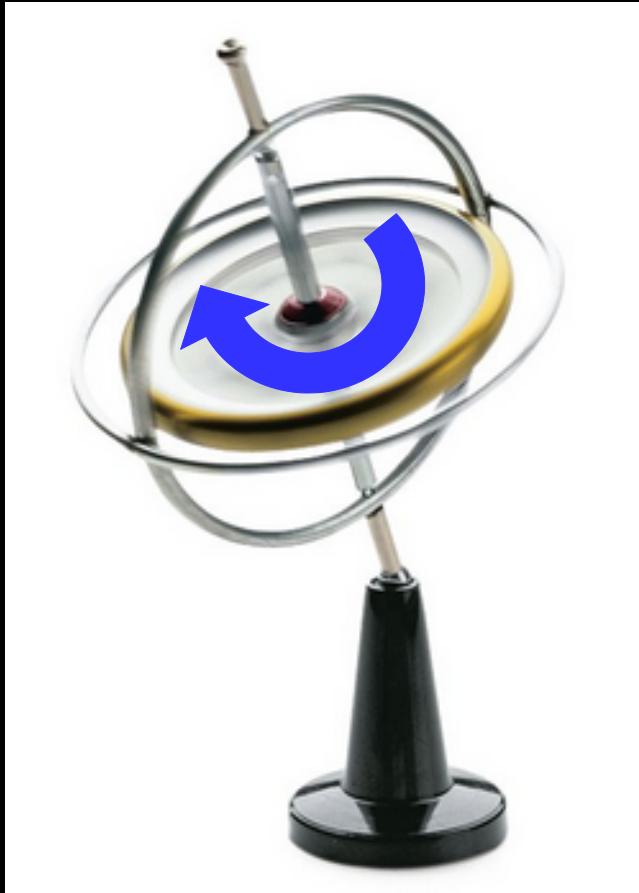
strength ~1.5 T, 3 T, 7 T

(earth magnetic field 25 ... 65 μT ,
factor 23k ... 280k)



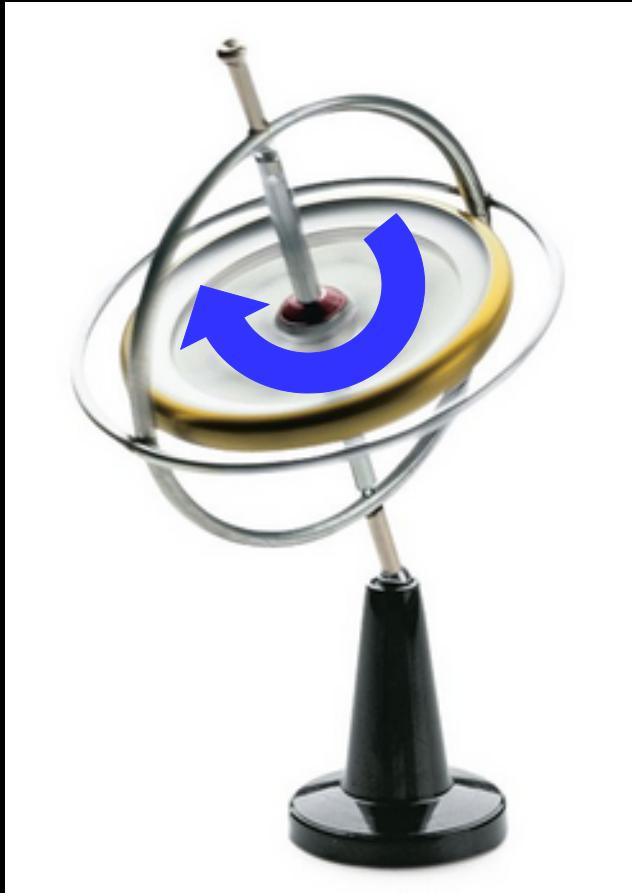
Proton Spins inside Magnetic Field

rotation: “spin”



Proton Spins inside Magnetic Field

rotation: “spin”

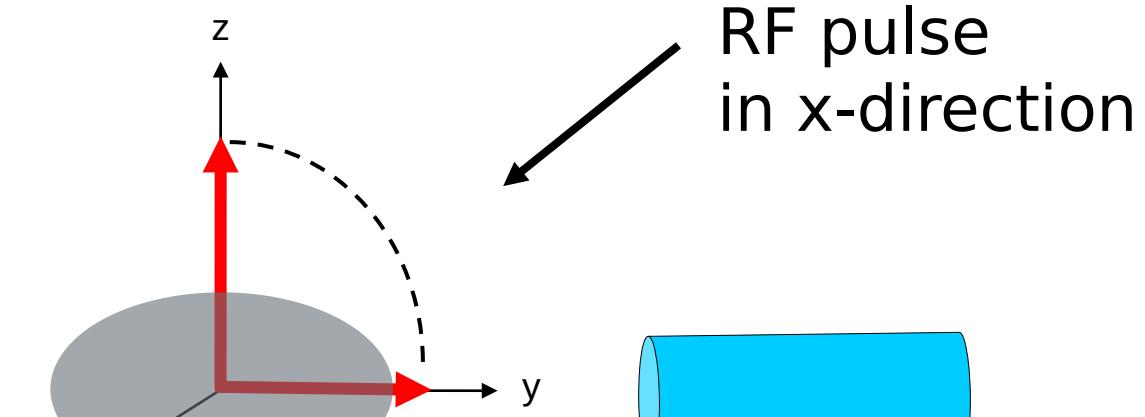
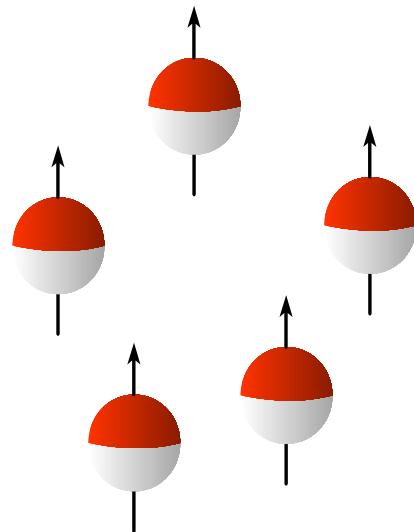


precession
with Larmor
frequency

$$\omega_L = \gamma \cdot \mathbf{B}$$

for protons:
42.58 MHz/T

Proton Spins inside Magnetic Field

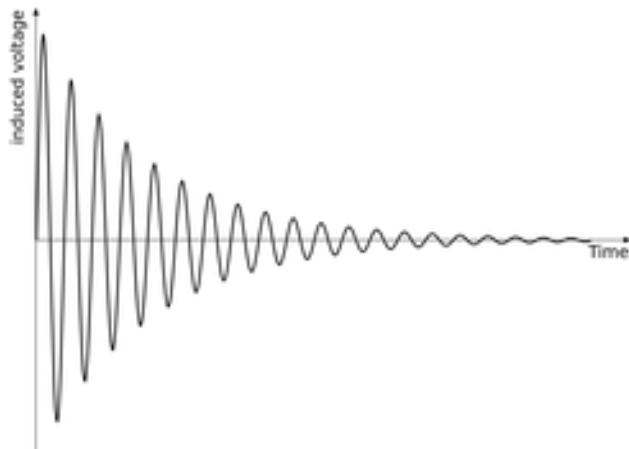


RF pulse
in x-direction

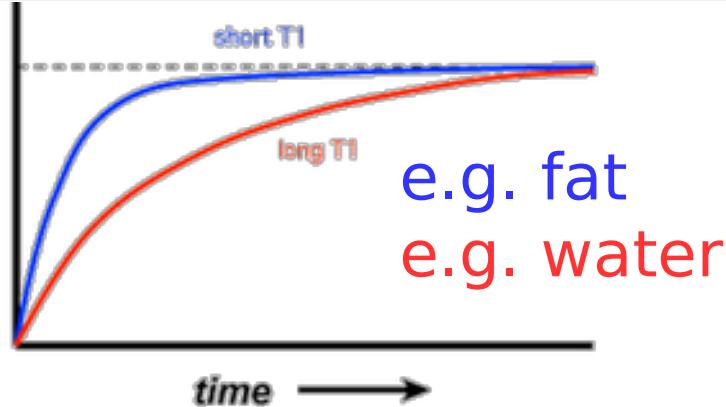
receiver coil
in y-direction:
induction

Proton Spins inside Magnetic Field

free induction decay

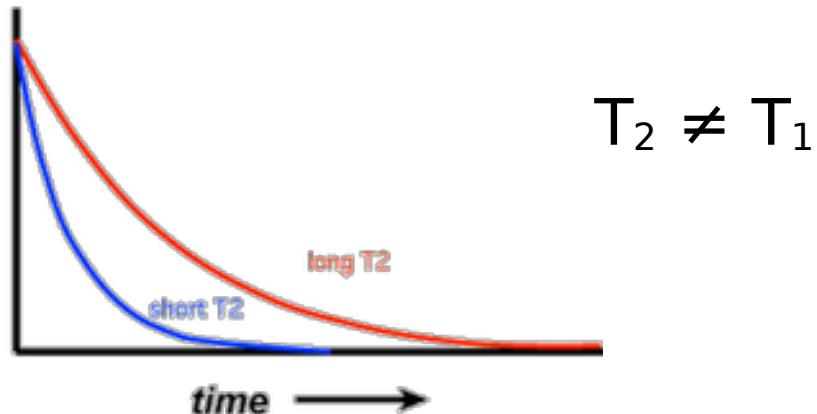


*Longitudinal
Magnetization
(M_z)*



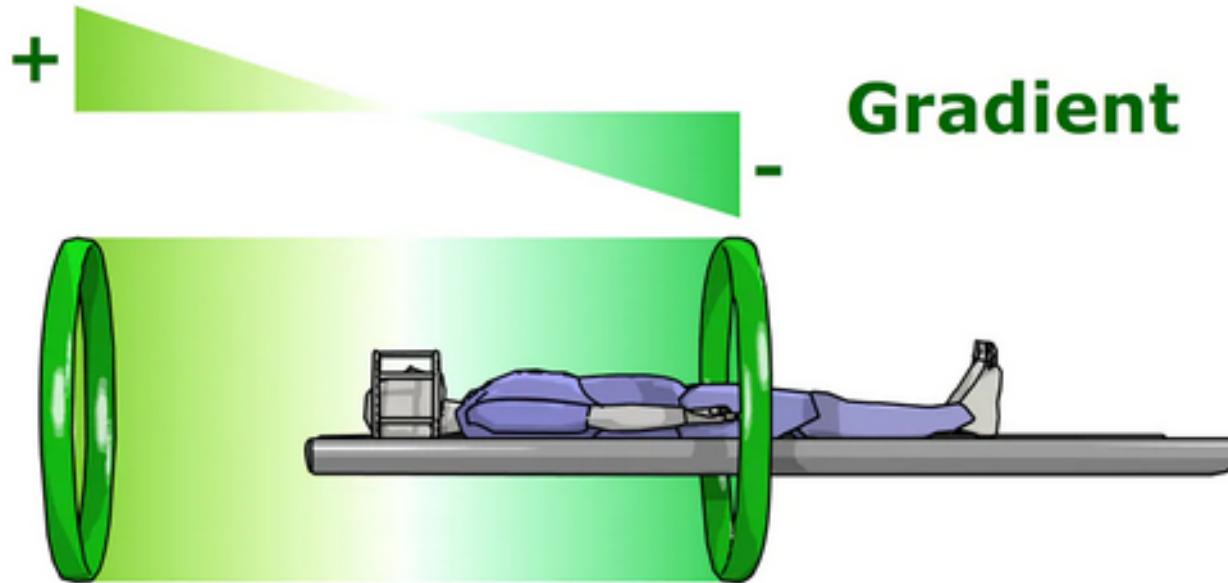
e.g. fat
e.g. water

*Transverse
Magnetization
(M_{xy})*



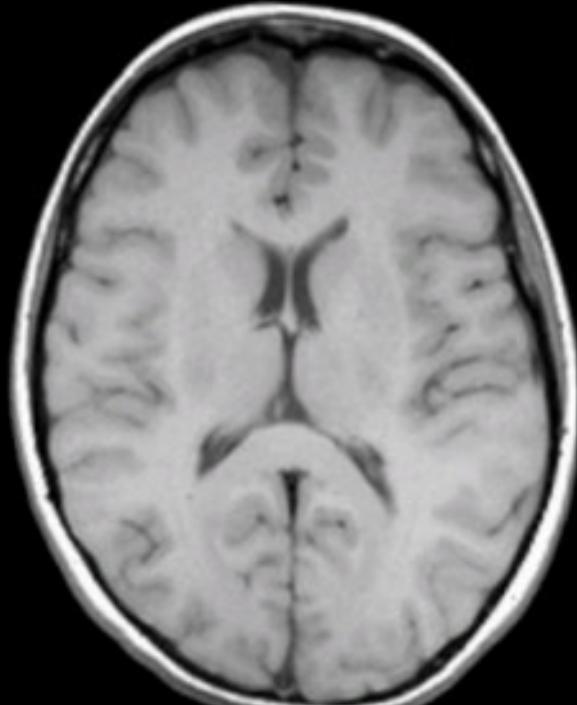
$T_2 \neq T_1$

Proton Spins inside Magnetic Field

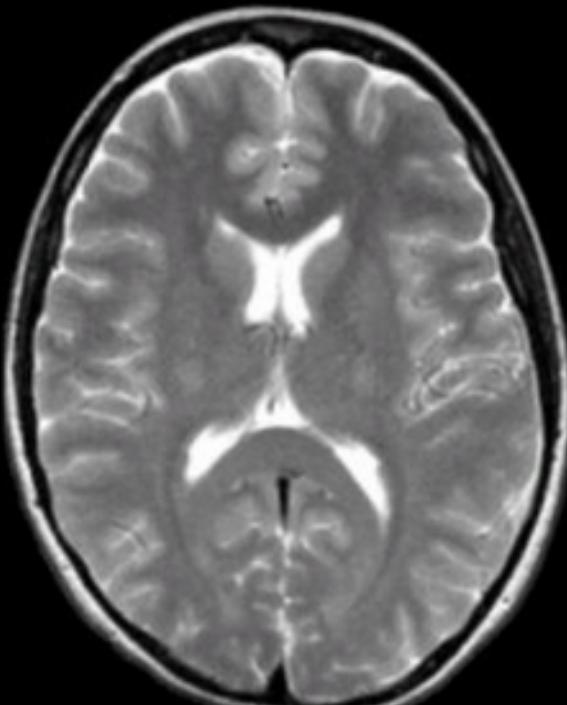


↔ ↔ ← ← ← $B_0 +$
Gradient

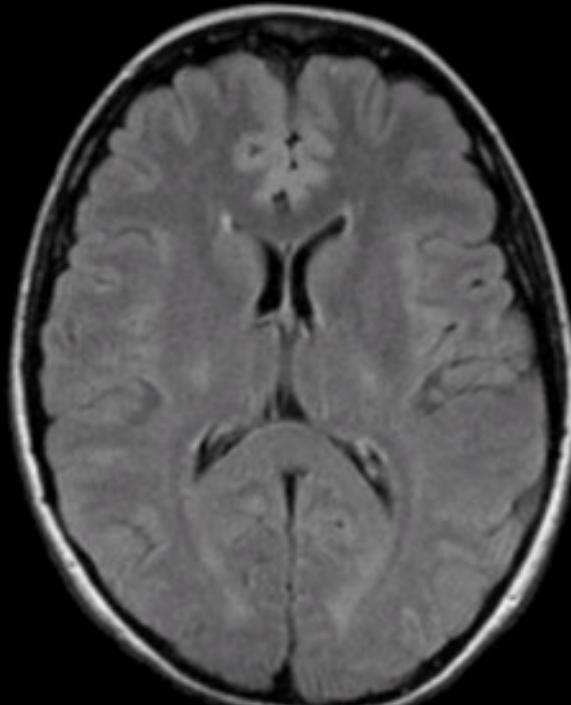
Structural MRI



T1-weighted

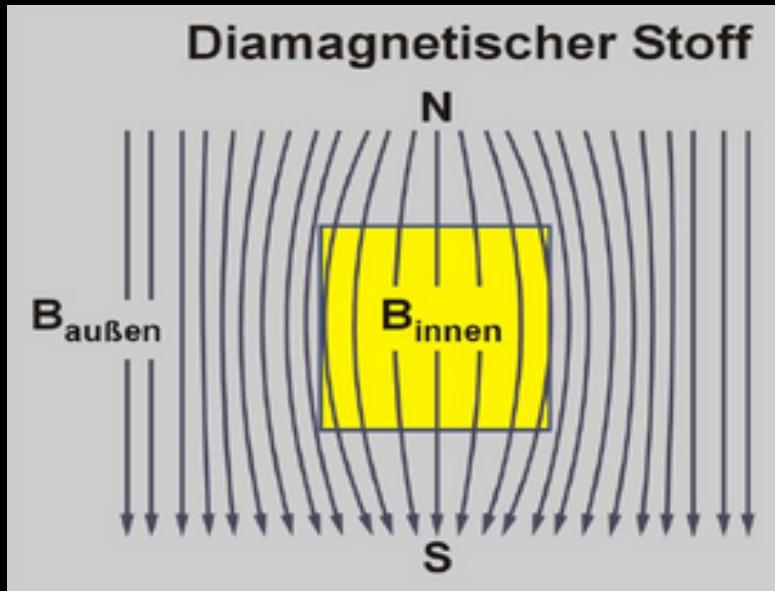


T2-weighted

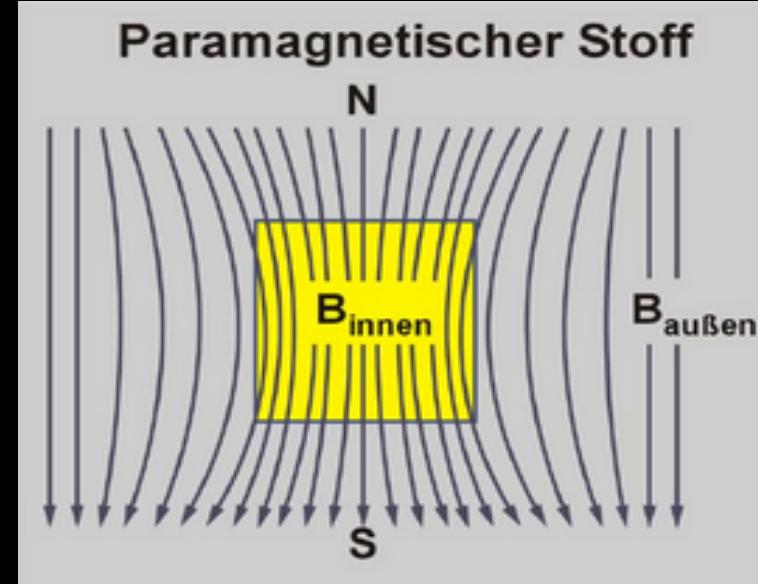


Flair

fMRI: Blood Oxygen Level Dependence



oxyHb



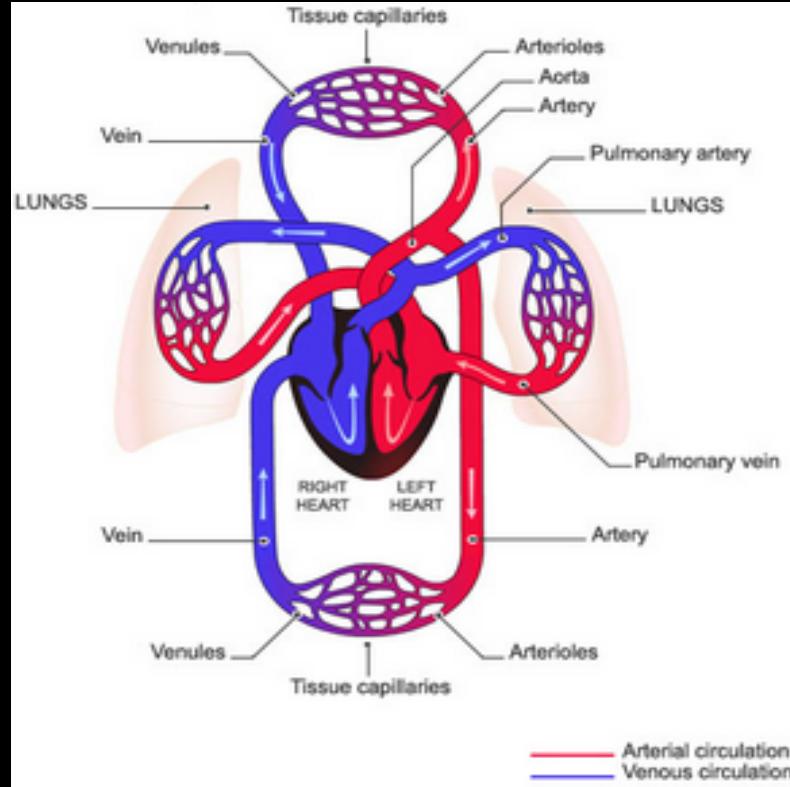
deoxyHb

intrinsic contrast agent **of blood!**

fMRI: Blood Oxygen Level Dependence

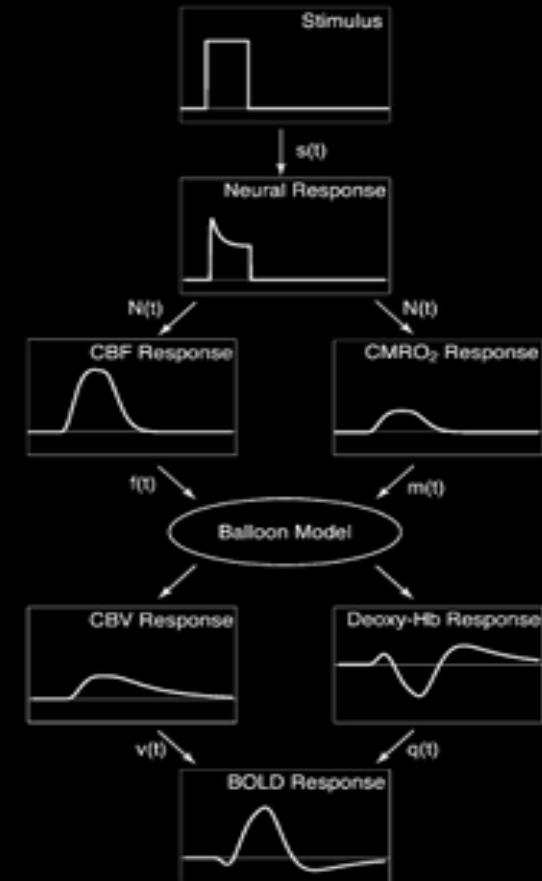
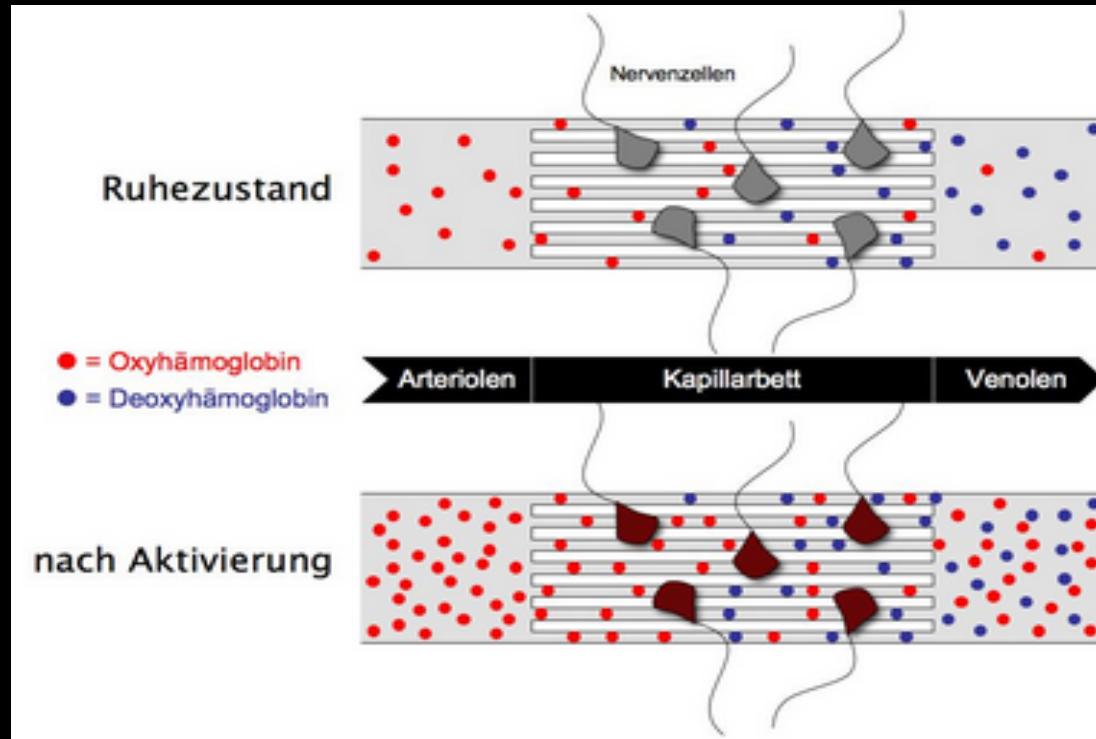
oxyHb
(diamagnetic):

- all electrons are **paired ($S = 0$)**
- **induced dipole moment**
- locally **reduced field**



deoxyHb
(paramagnetic):

- **four unpaired electrons (spin $S = 2$)**
- **permanent dipole moment**
- locally **increased field**

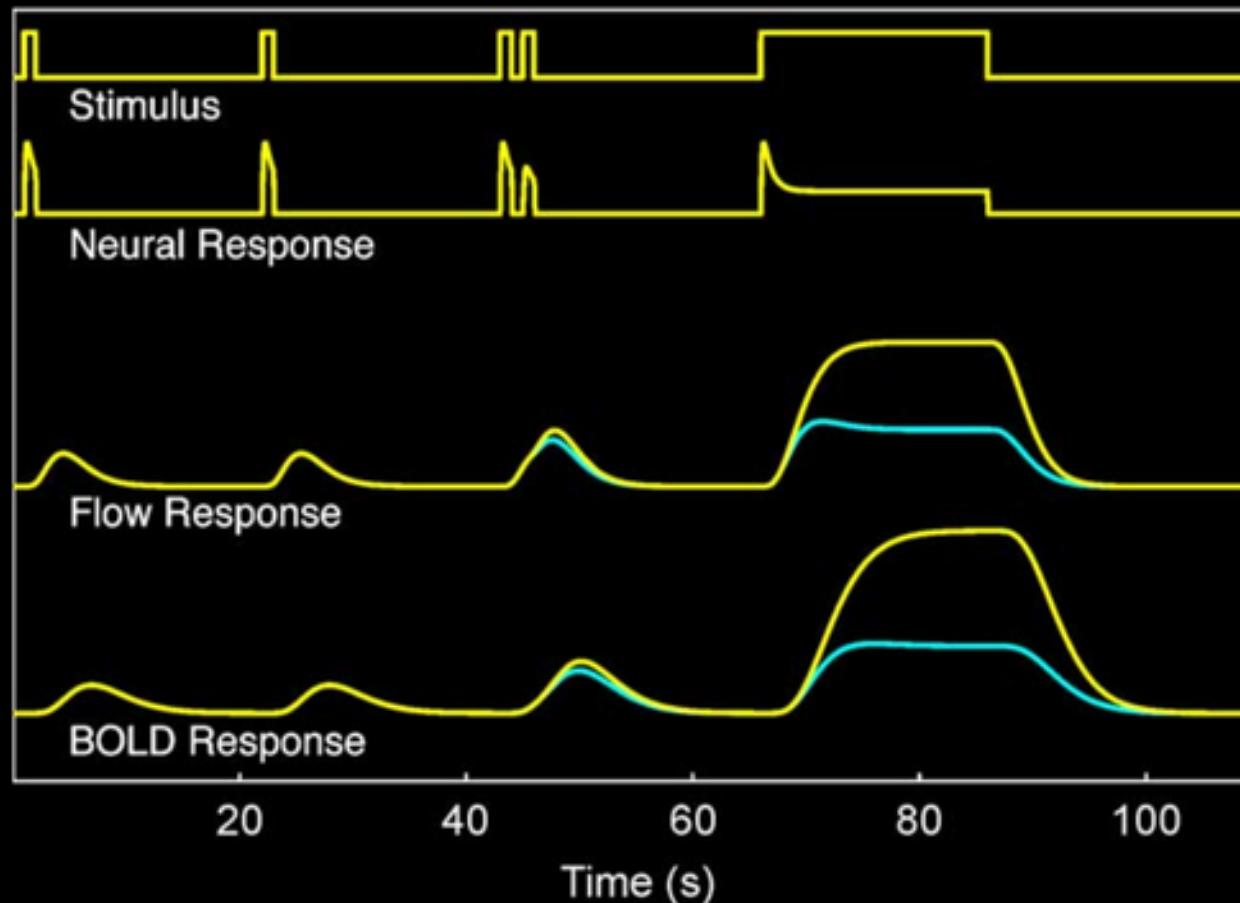


hemodynamic response **over-compensates**
increased oxygen consumption

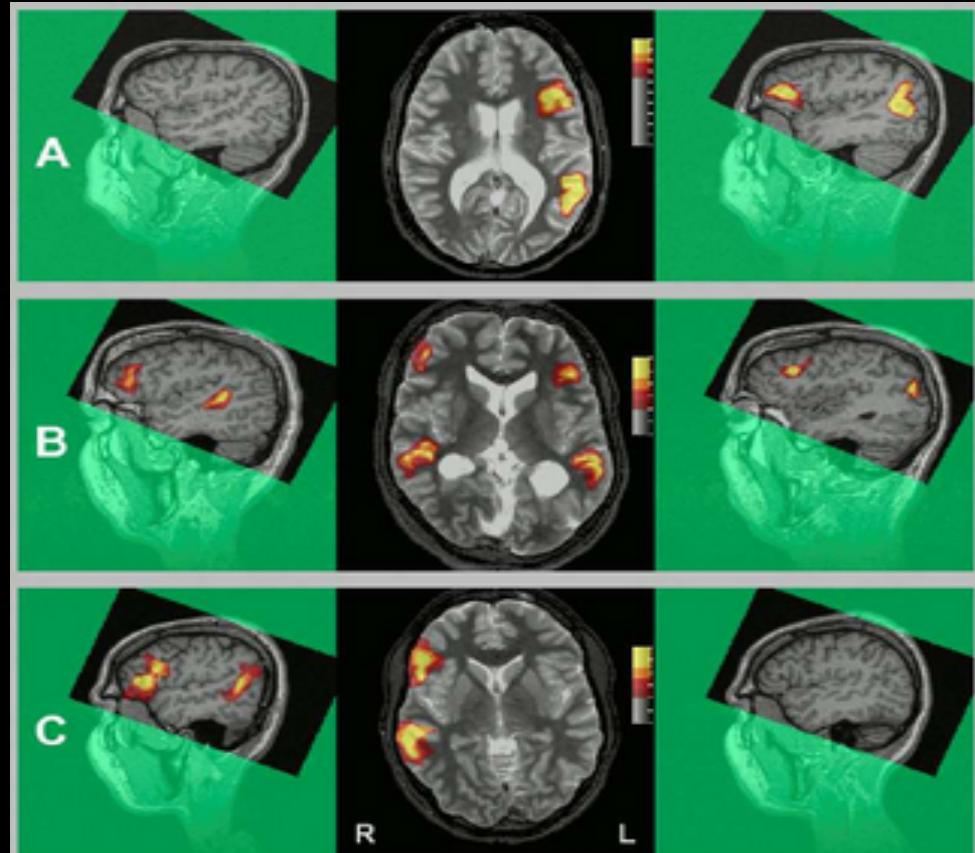
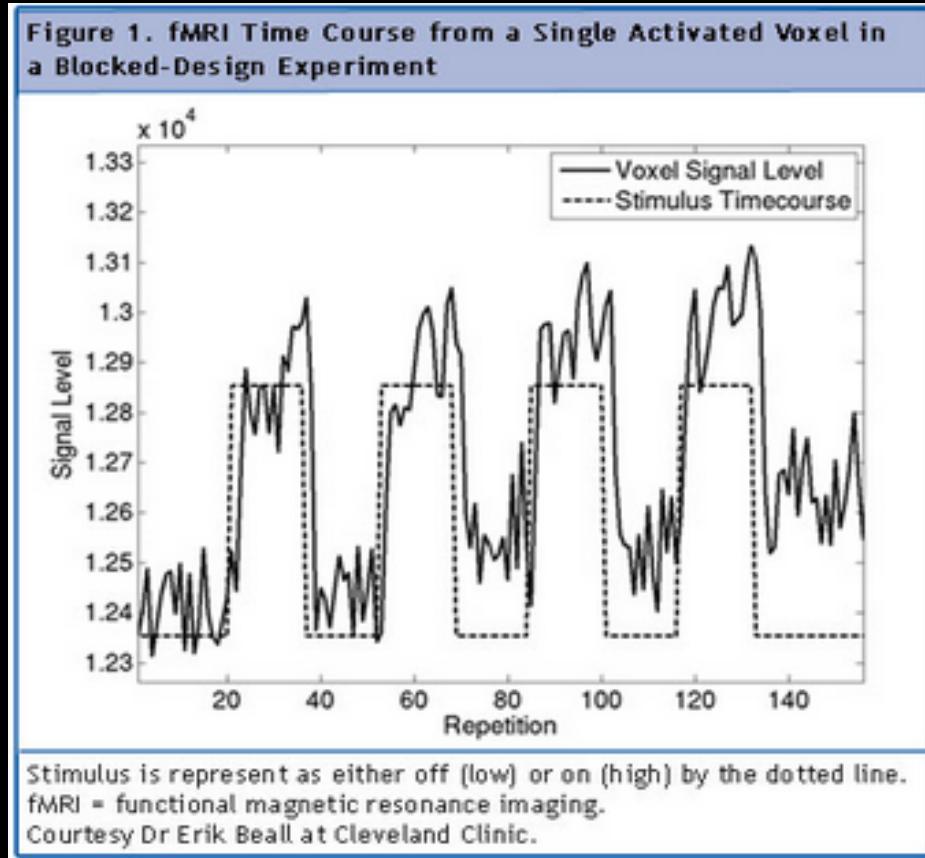
fMRI: Blood Oxygen Level Dependence

B.

BOLD and Neural Nonlinearity



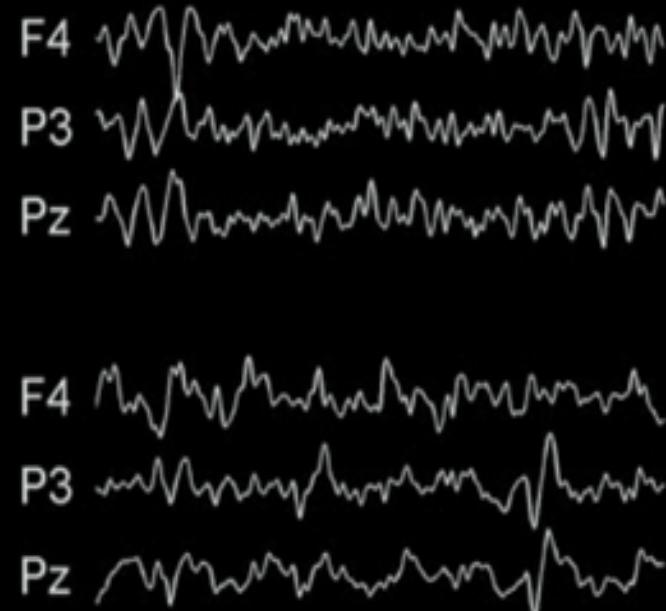
fMRI: Blood Oxygen Level Dependence



BOLD-fMRI with block design

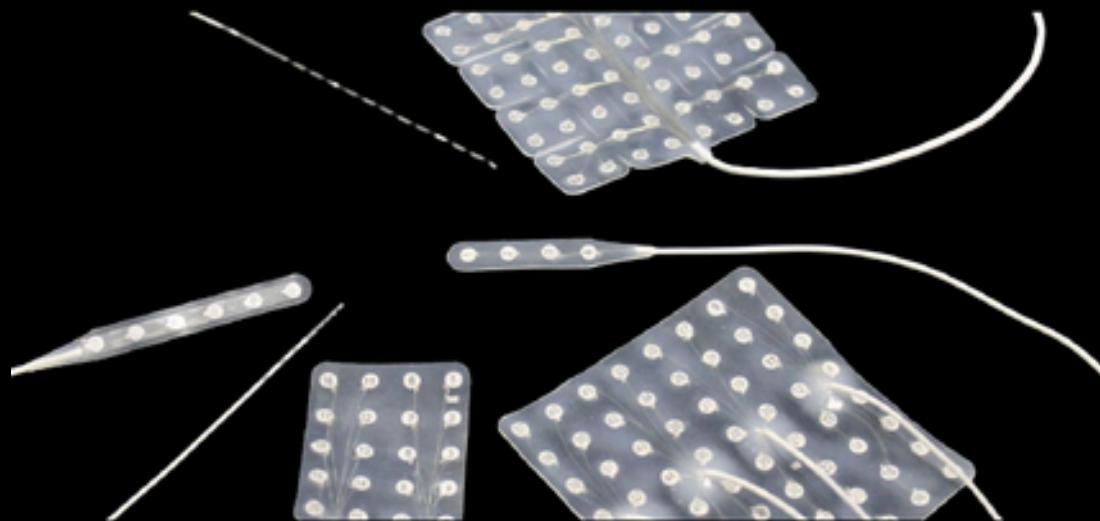
Gutbrod et al., J. Neuroimaging (2011)

Electroencephalography (EEG)



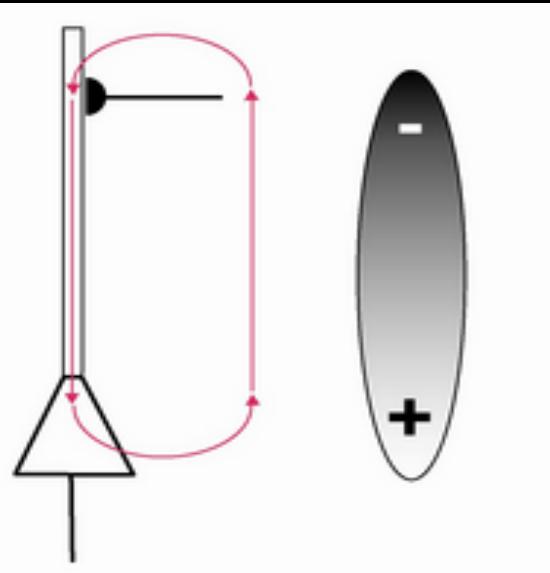
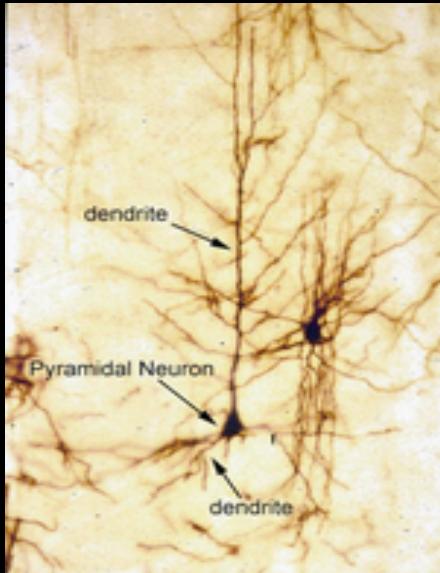
Brain Potentials

Brain Potentials



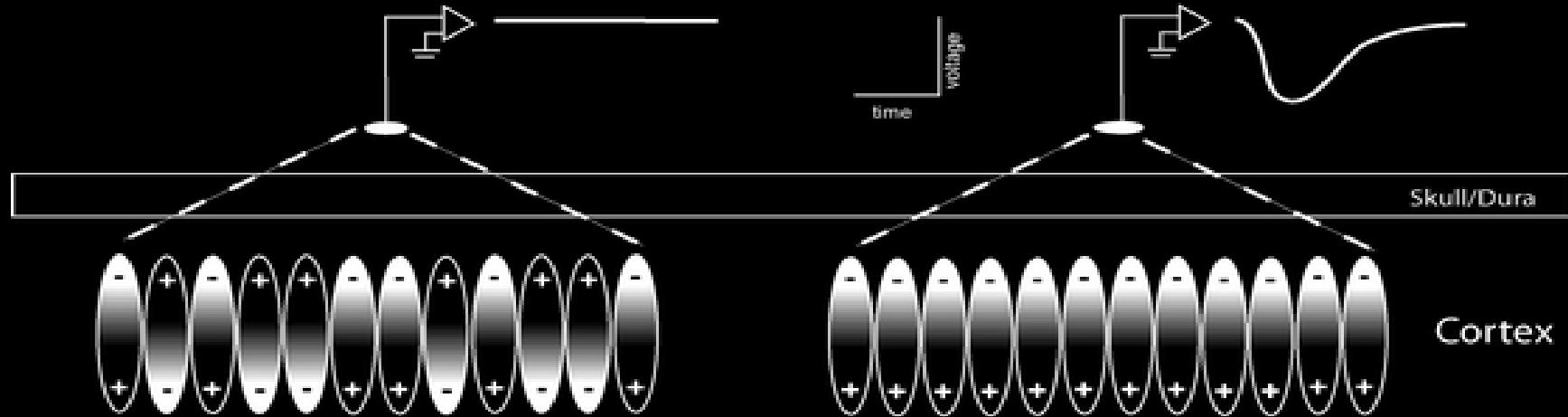
	scalp EEG	intracranial EEG
Signal quality	✗	✓
Artifacts	✗	✓
Deep lying structures	✗	✓
Spatial resolution	✗	✓
Temporal resolution	?	✓
Invasiveness	✓	✗
Spatial coverage	✓	✗

Brain Potentials

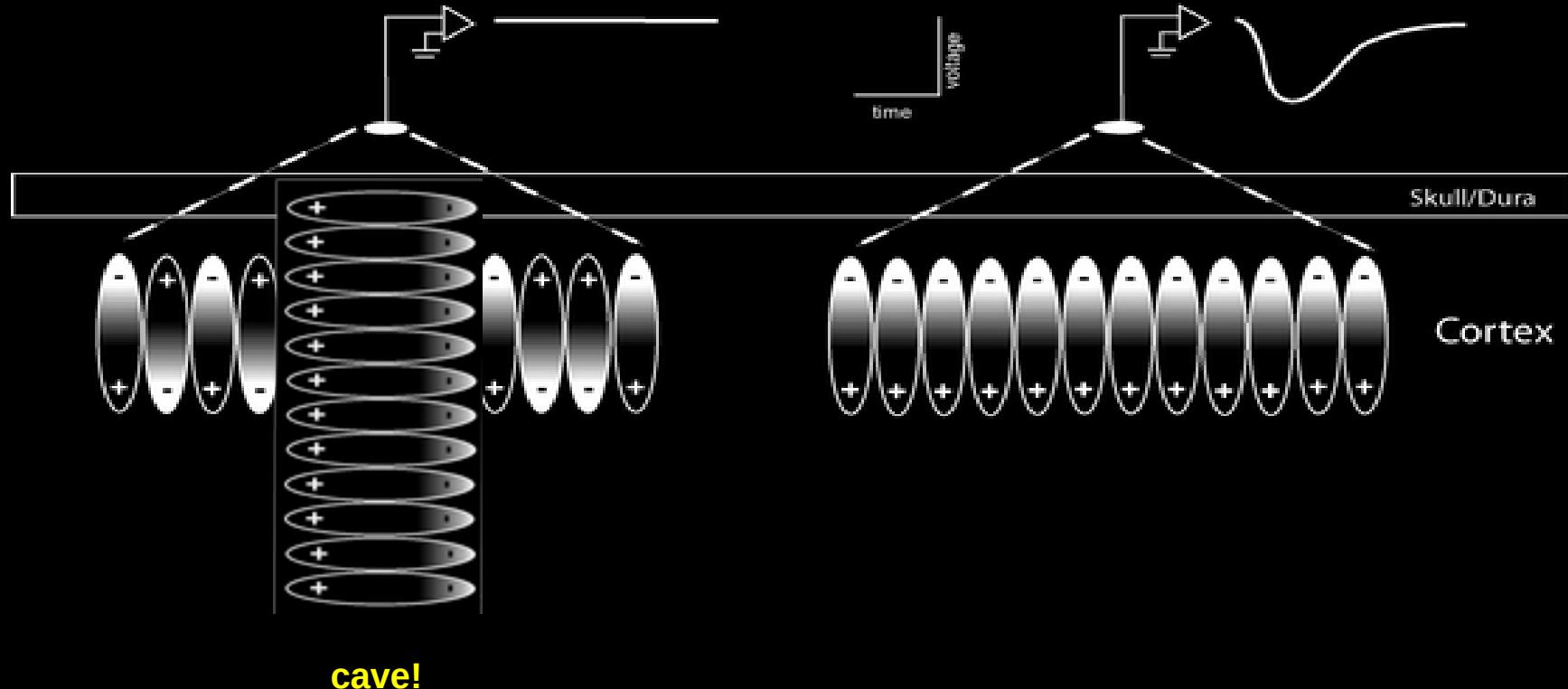


electrical **dipoles**

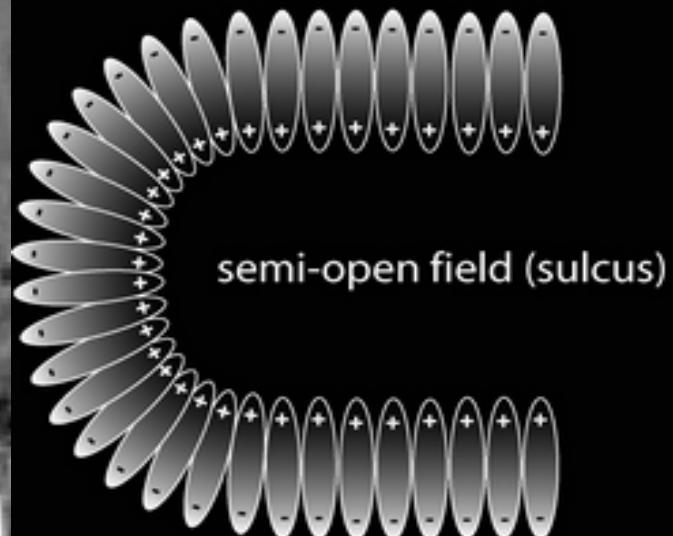
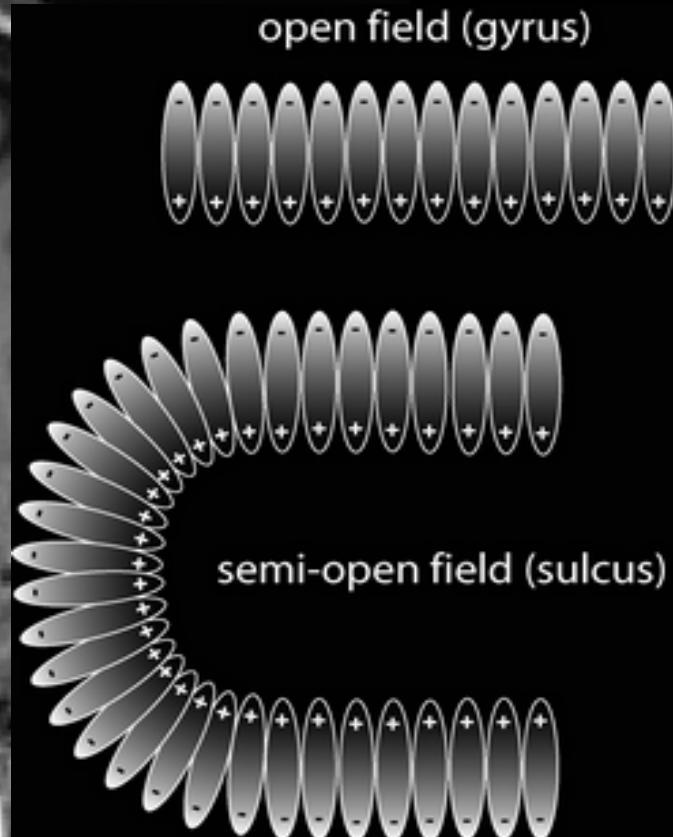
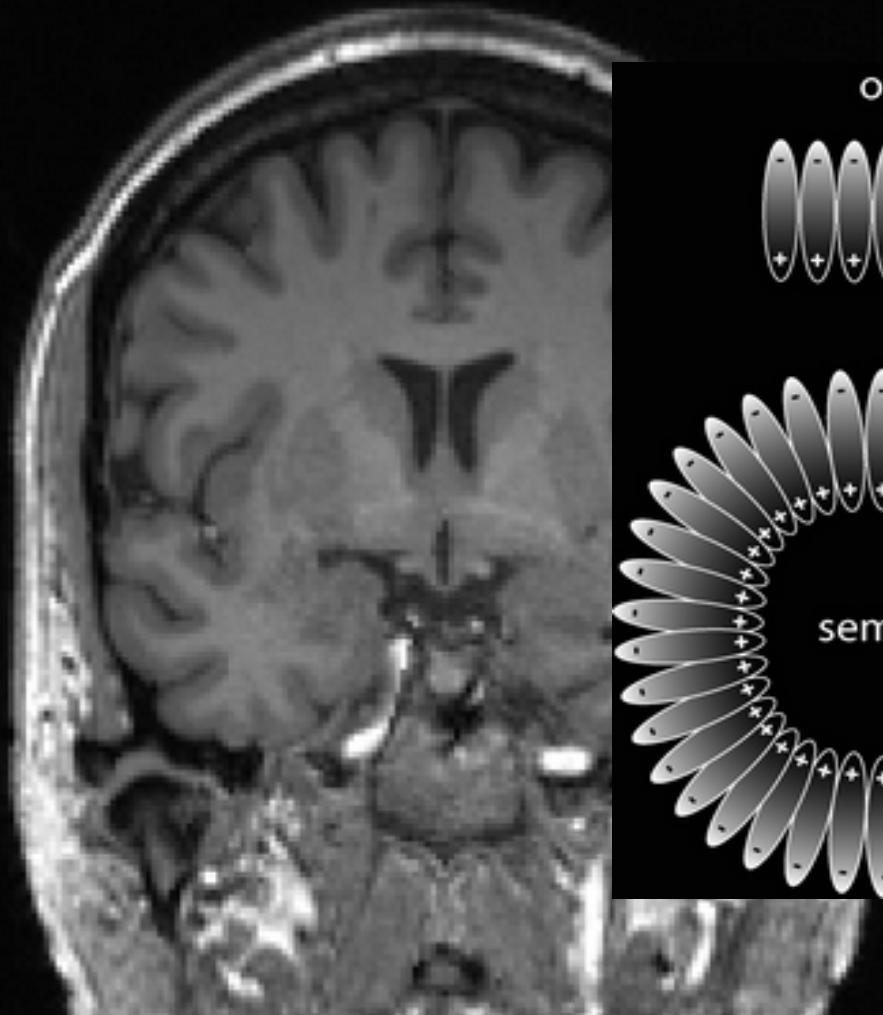
Brain Potentials



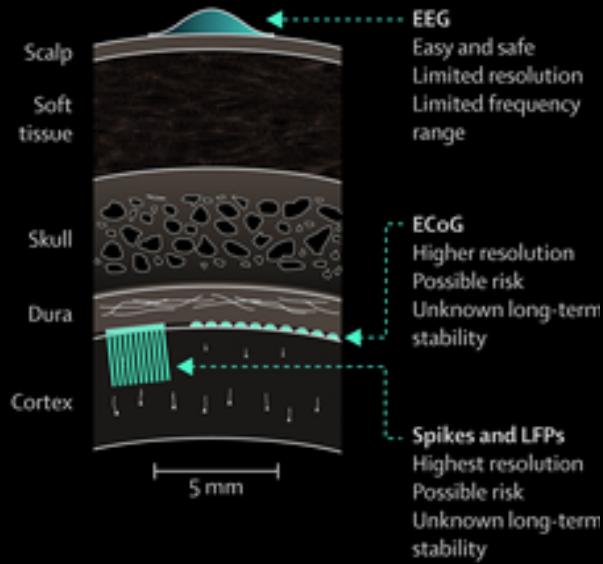
Brain Potentials



Brain Potentials

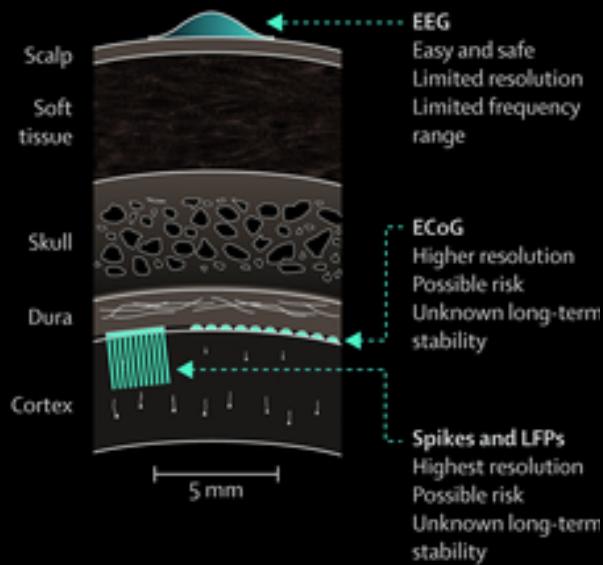


Brain Potentials



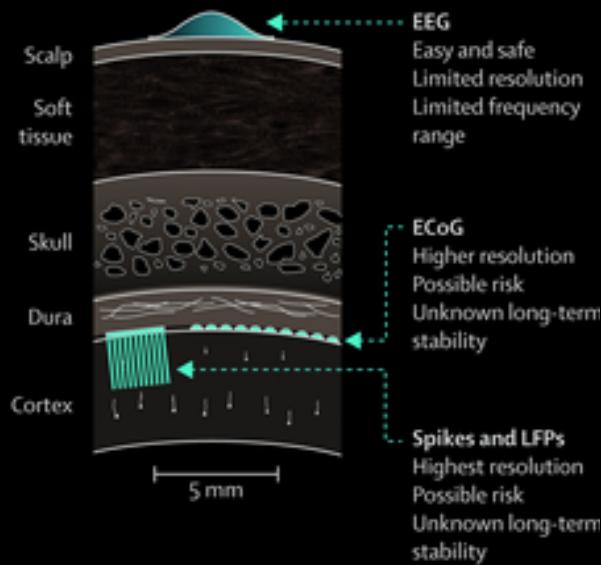
Brain Potentials

A EEG tonic-clonic seizure

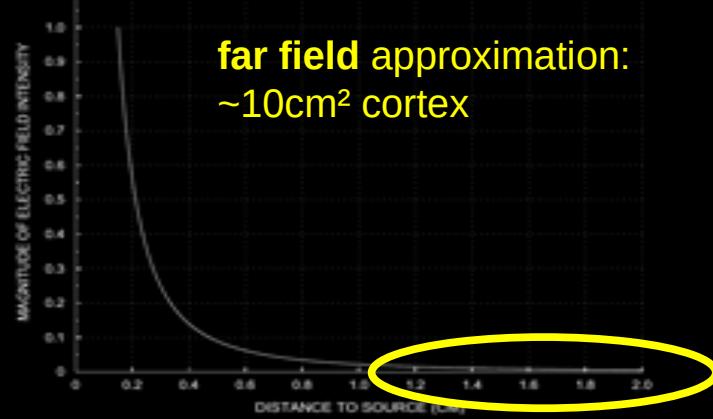


Brain Potentials

A EEG tonic-clonic seizure

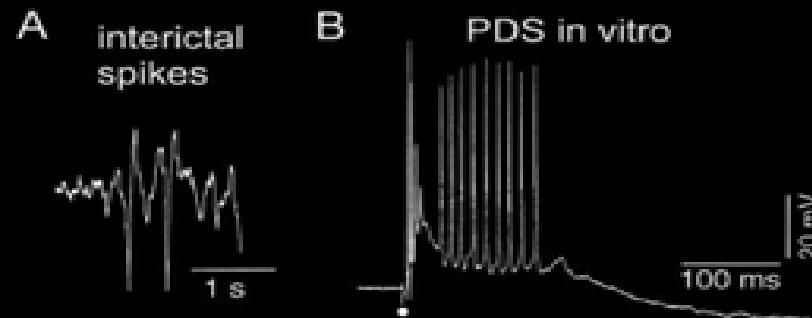
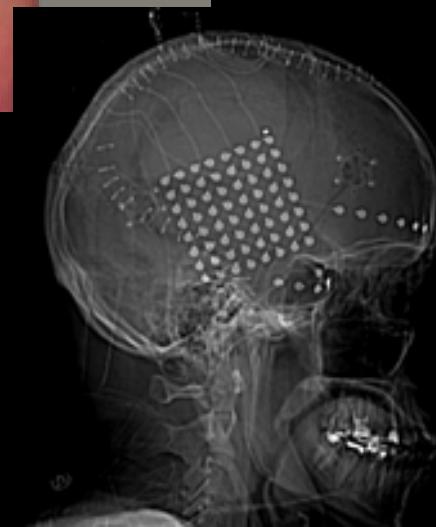
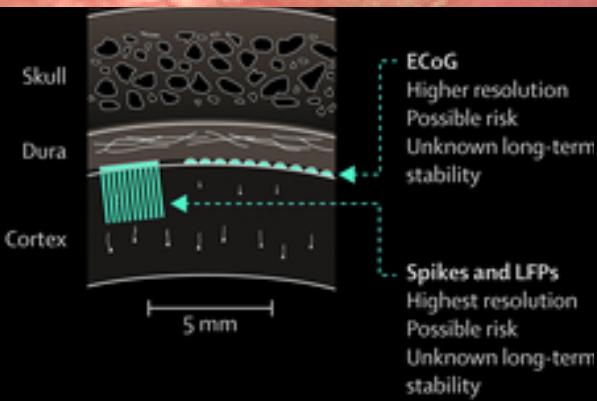
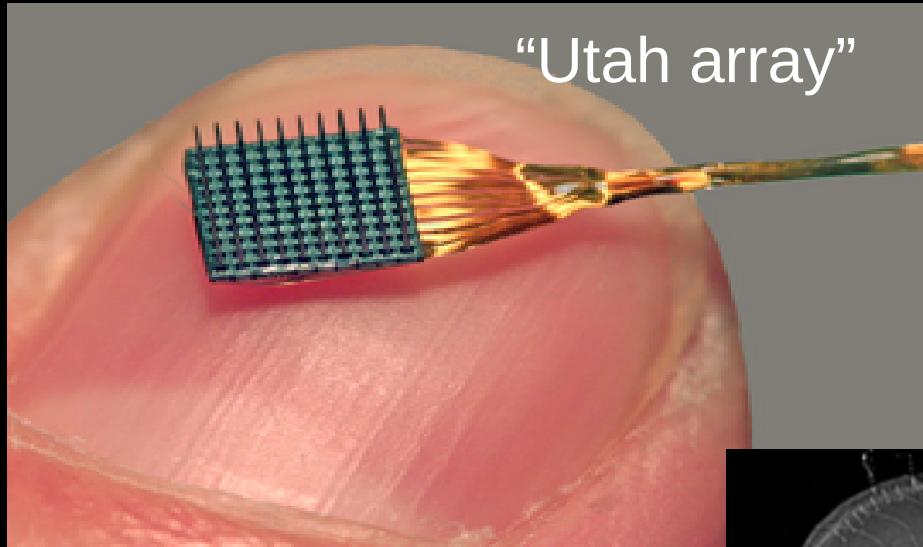


Letter to the Editor / Clinical Neurophysiology 120 (2009) 1873–1875

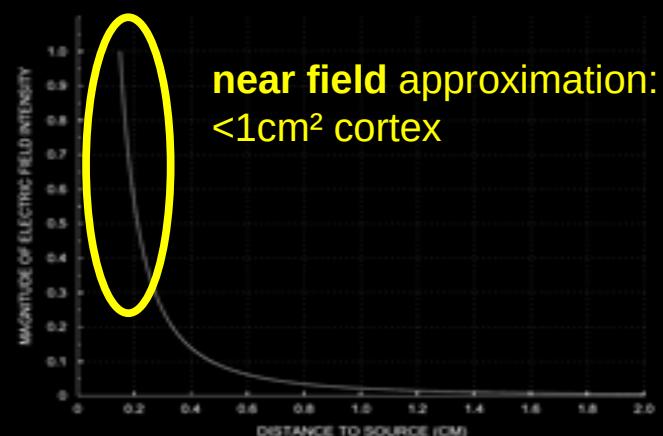


far field approximation:
~10cm² cortex

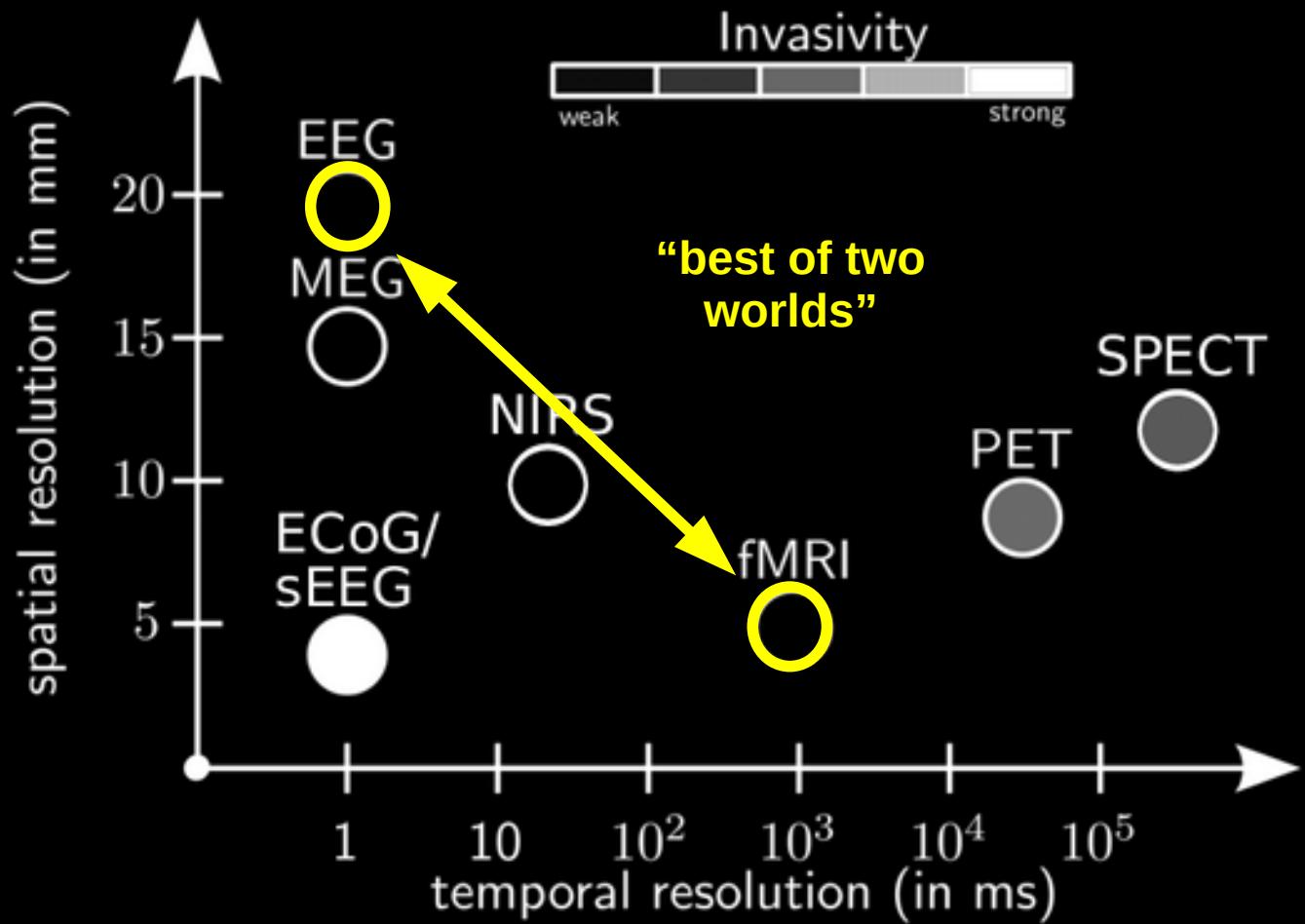
Brain Potentials



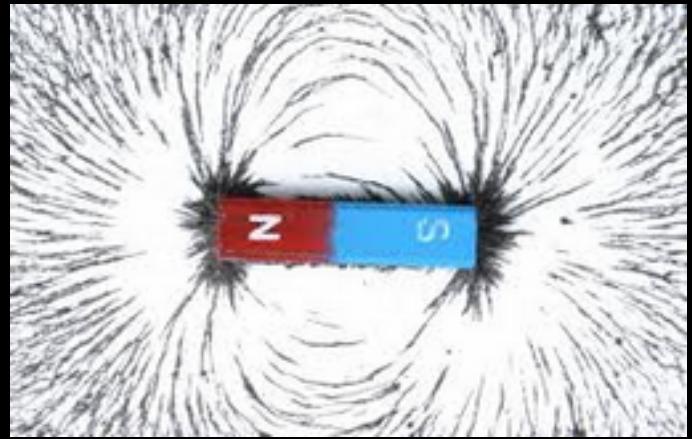
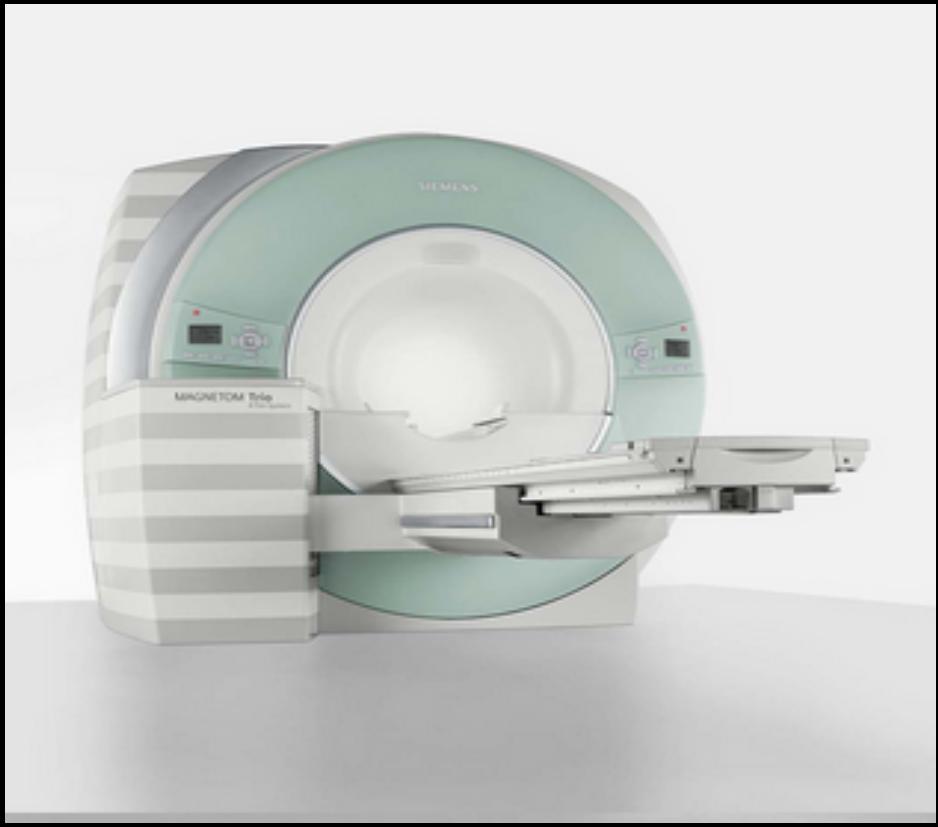
Letter to the Editor / Clinical Neurophysiology 120 (2009) 1873–1875



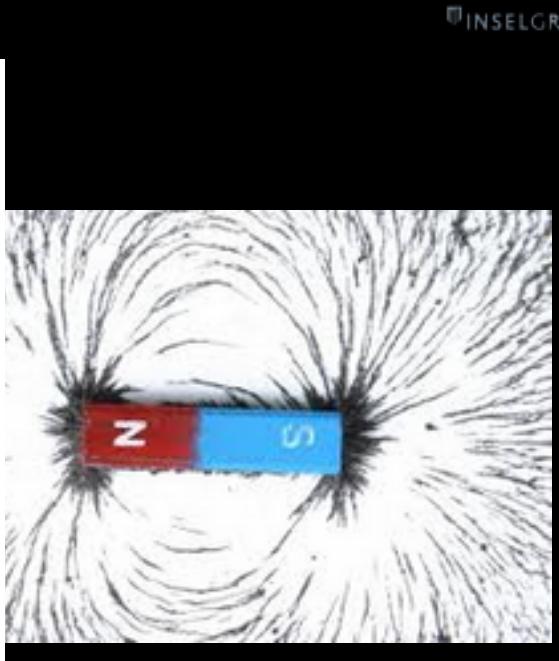
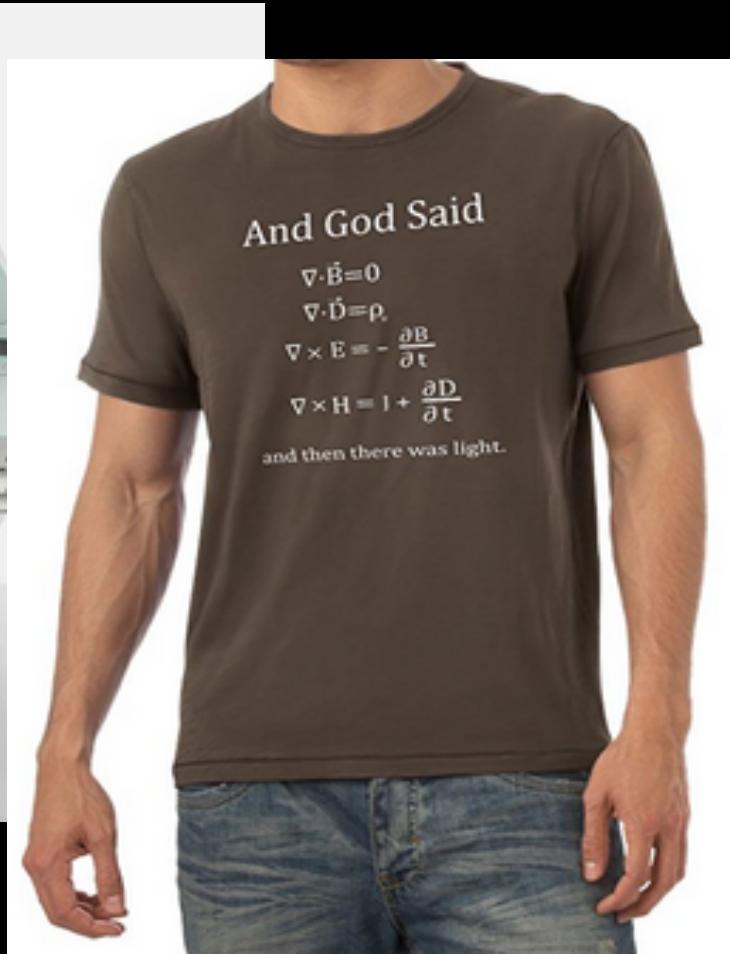
Simultaneous EEG-fMRI



Simultaneous EEG-fMRI

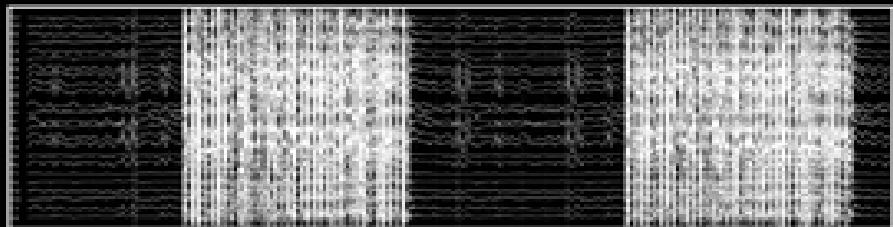


Simultaneous EEG-fMRI



Maxwell's equations:
Faraday's law of induction

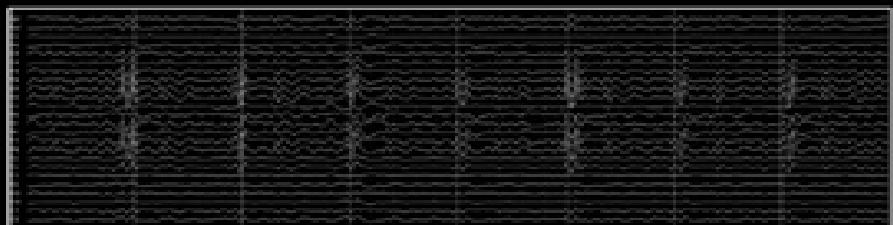
Simultaneous EEG-fMRI



Raw EEG inside Scanner



Template
artifact
subtraction

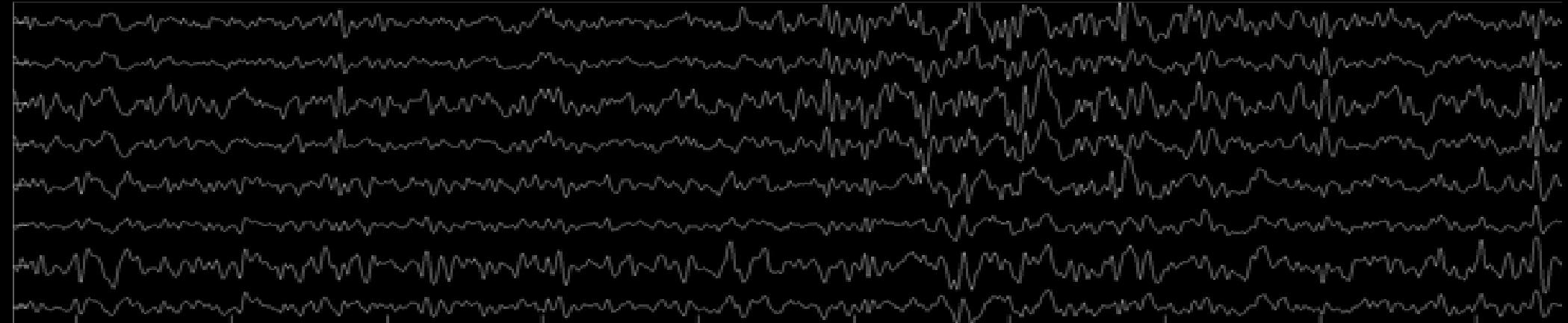


Corrected EEG inside Scanner

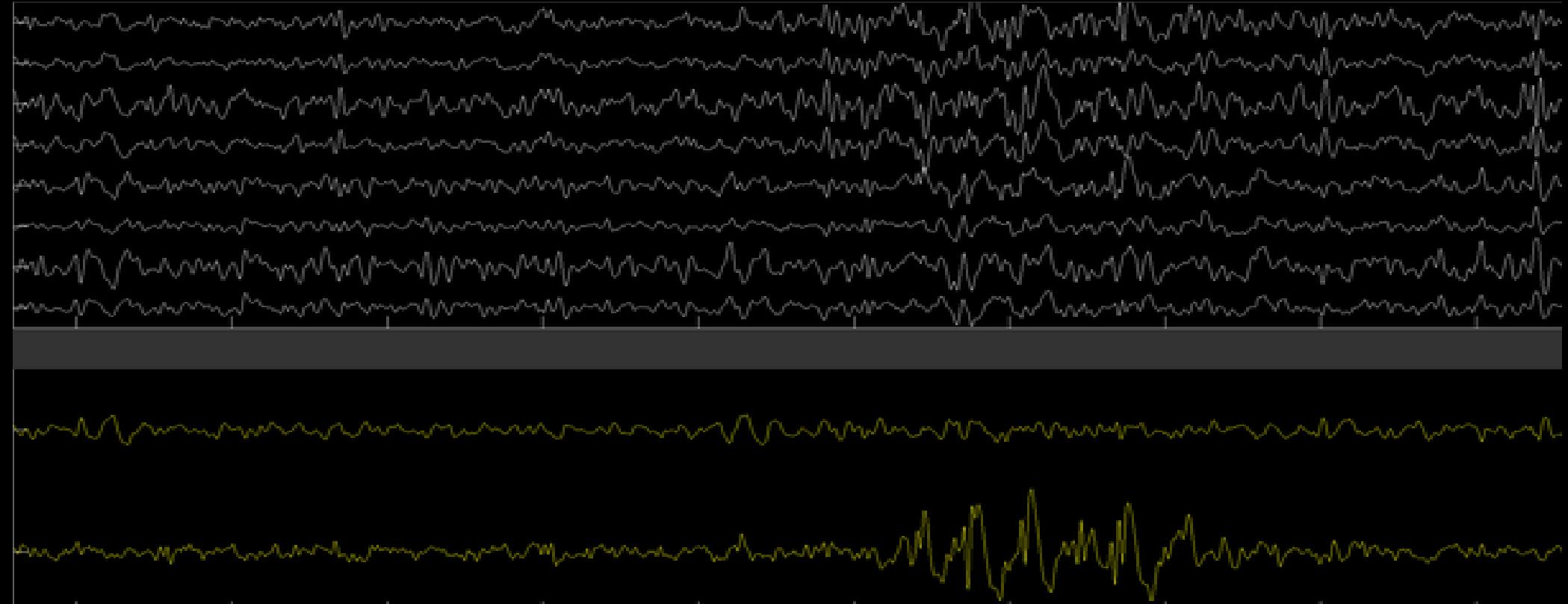
Simultaneous EEG-fMRI



Simultaneous EEG-fMRI

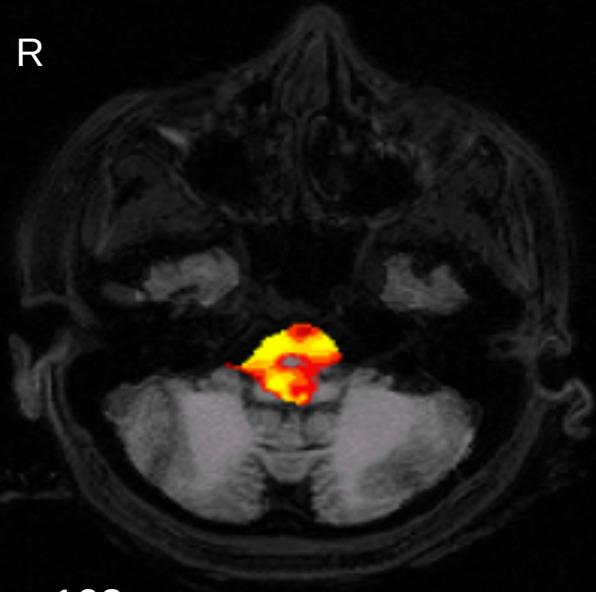


Simultaneous EEG-fMRI

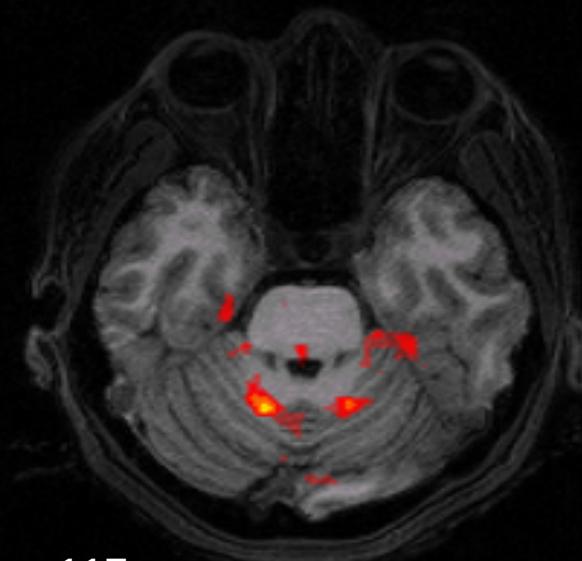


Simultaneous EEG-fMRI

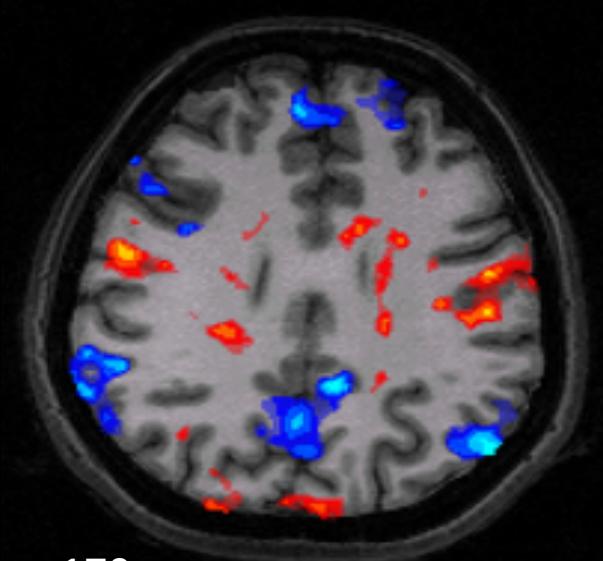
R



103



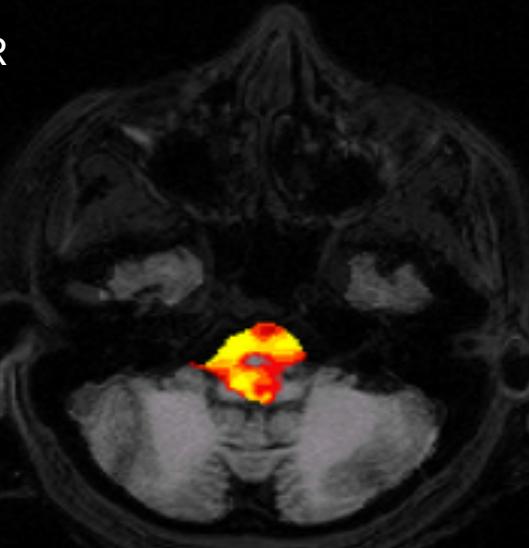
117



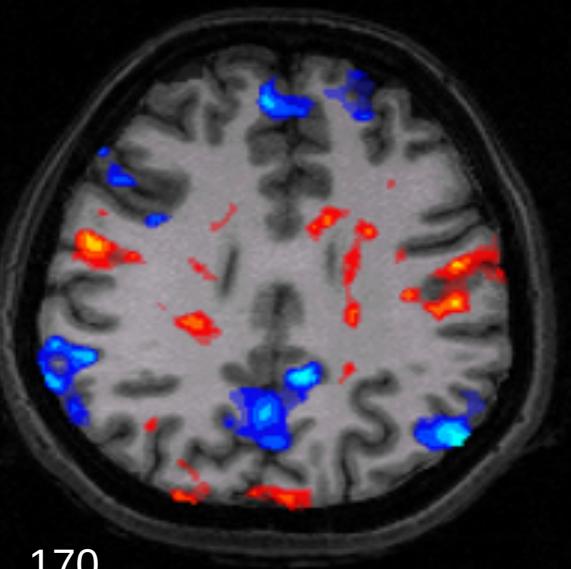
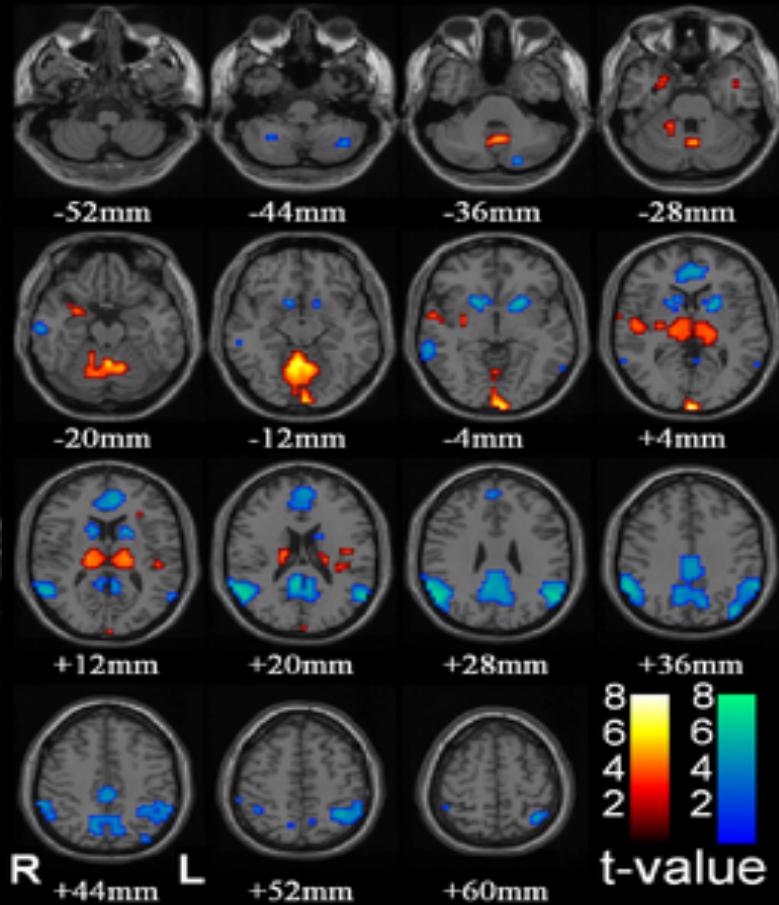
170

Simultaneous EEG-fMRI

R



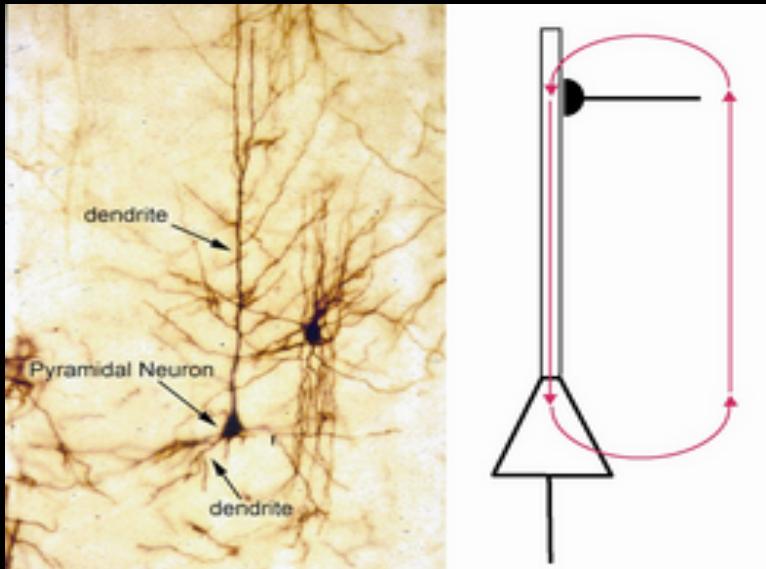
103



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Magnetoencephalography (MEG)

Brain Currents

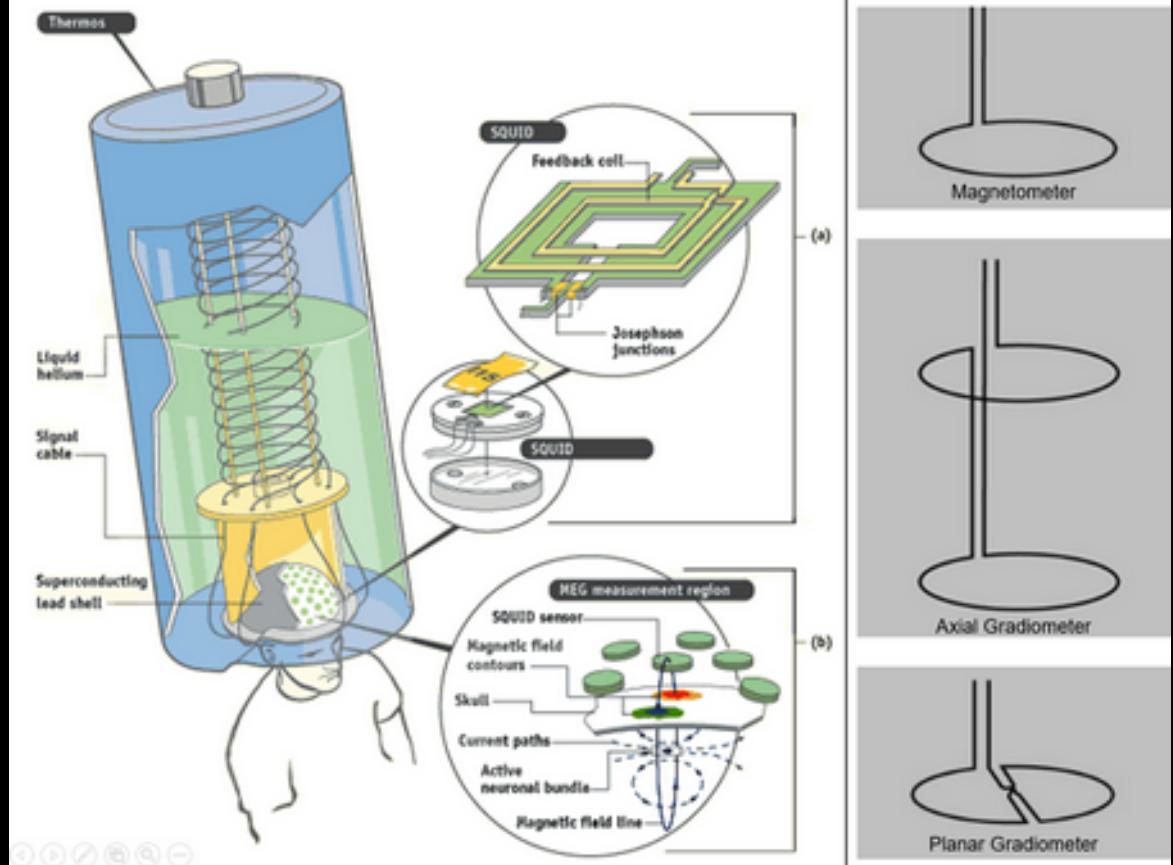


electrical **currents**

magnetic field change
 $\sim 10^{-15}$ T

(earth magnetic field
 $\sim 25 \dots 65 \mu\text{T}$)

Brain Currents



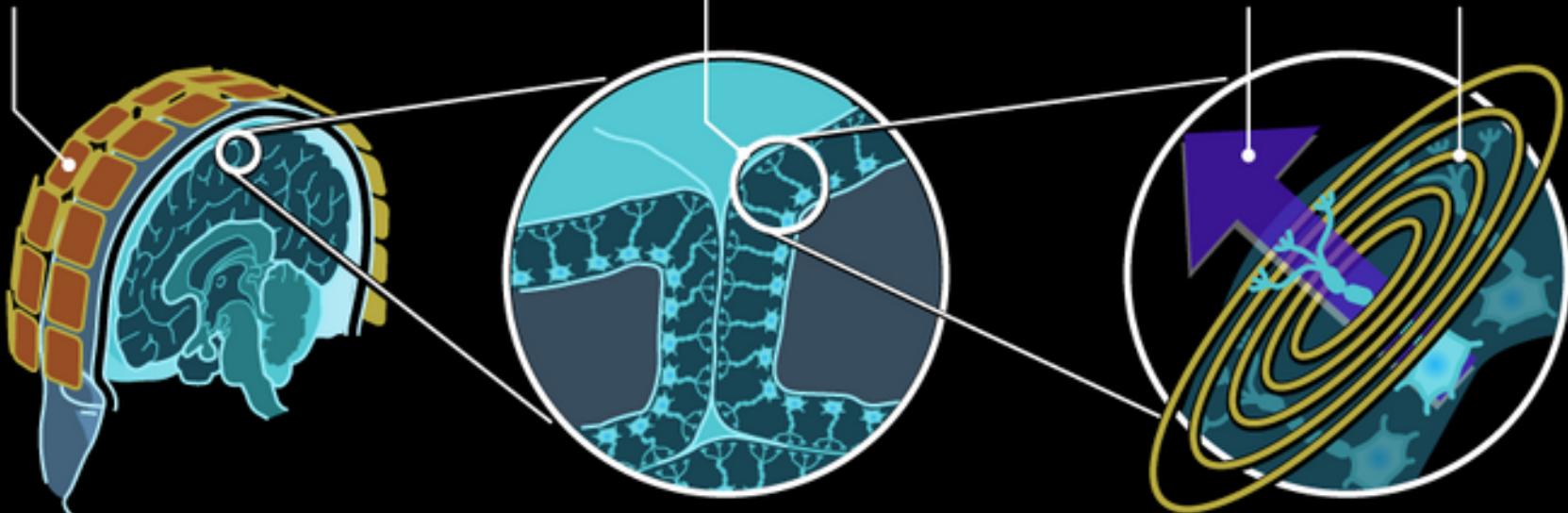
Brain Currents

SQUID* sensor array aligned to cortical surface of the brain

Axons in the cortical surface of the brain

Direction of electric current in active axon

SQUID sensor detects magnetic field of current



* Superconducting Quantum Interface Device

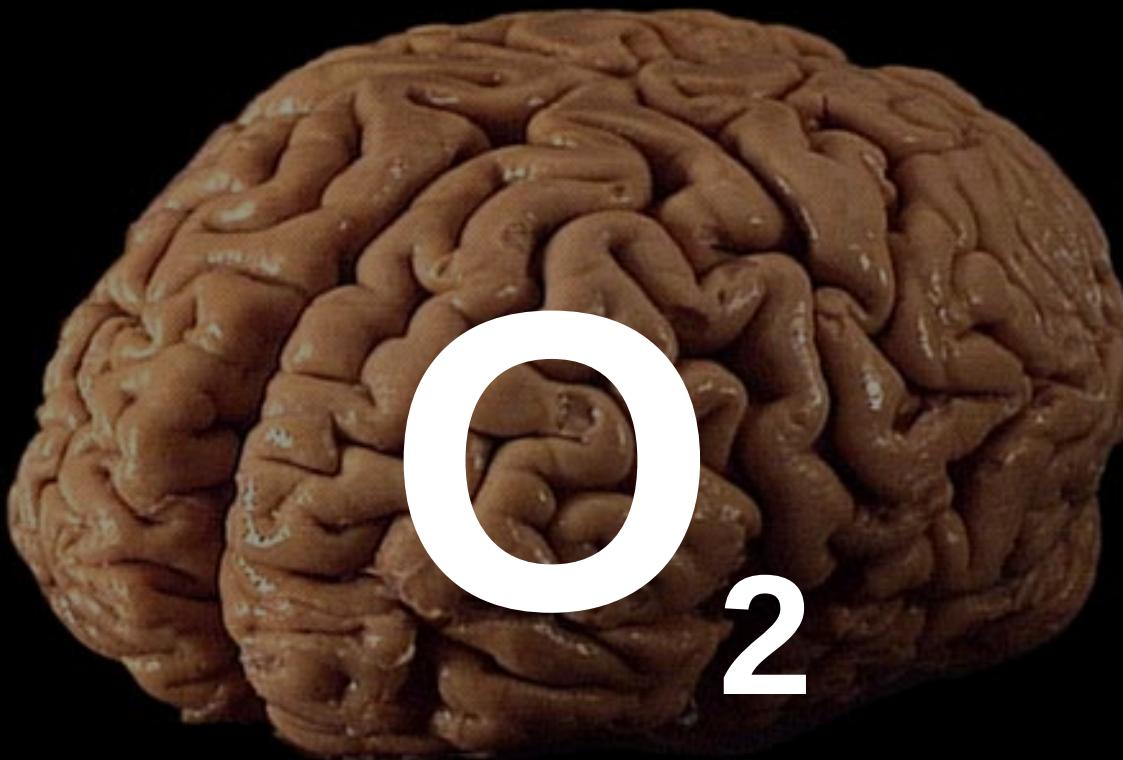
HUMANCONNECTOME.ORG

Near InfraRed Spectroscopy (NIRS)

Cerebral oxygenation



insufficient supply:
**danger of severe
brain damage!**



**neuro-vascular
coupling:**
indirect measure
for neural activation

Cerebral oxygenation



perfusion MRI
functional MRI

Cerebral oxygenation



difficult to transfer
immobile patients

perfusion MRI
functional MRI

Cerebral oxygenation

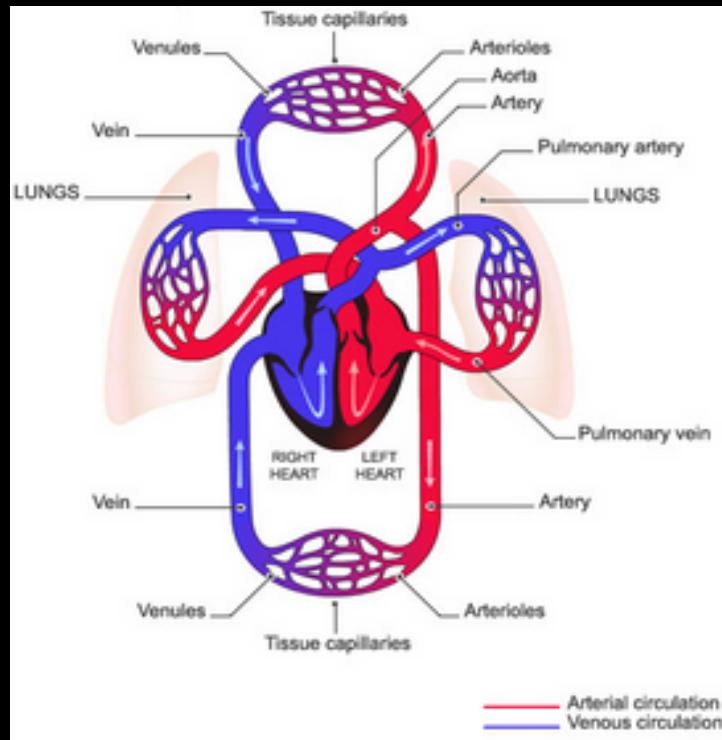


perfusion MRI
functional MRI

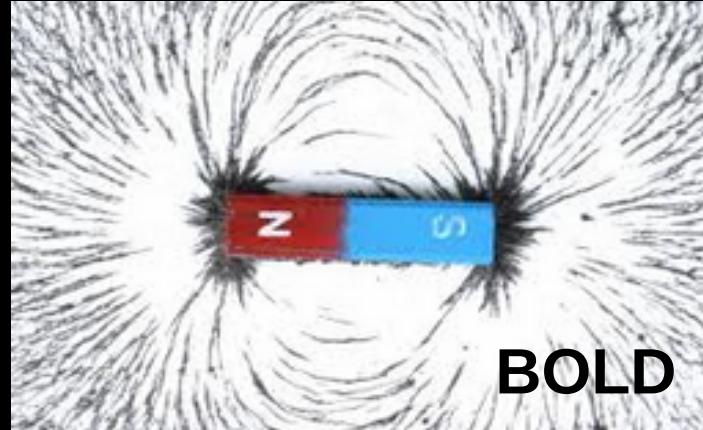
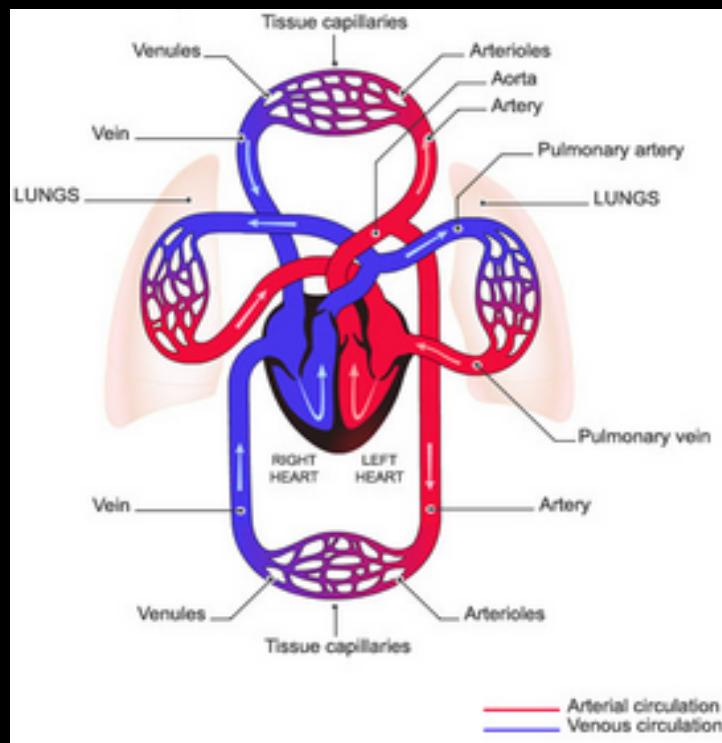
difficult to transfer
immobile patients

only snapshot info

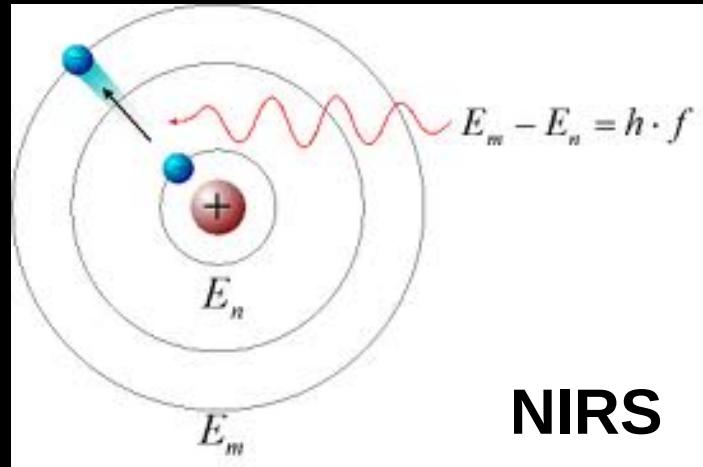
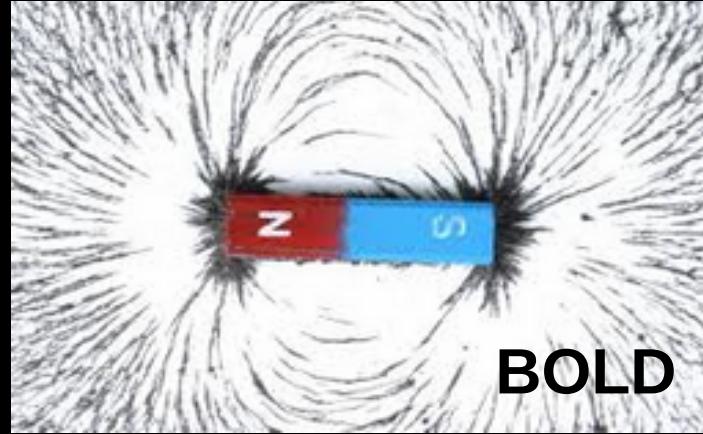
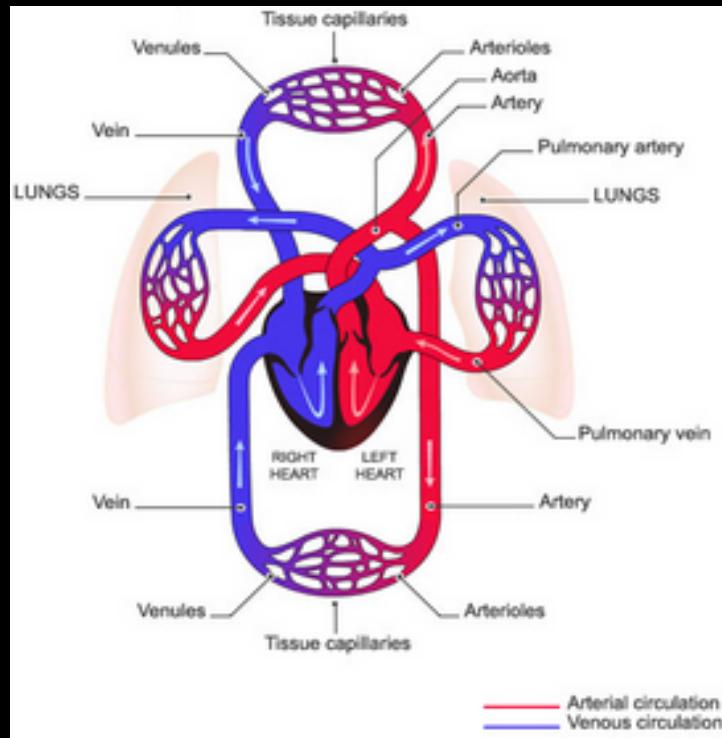
Cerebral oxygenation



Cerebral oxygenation



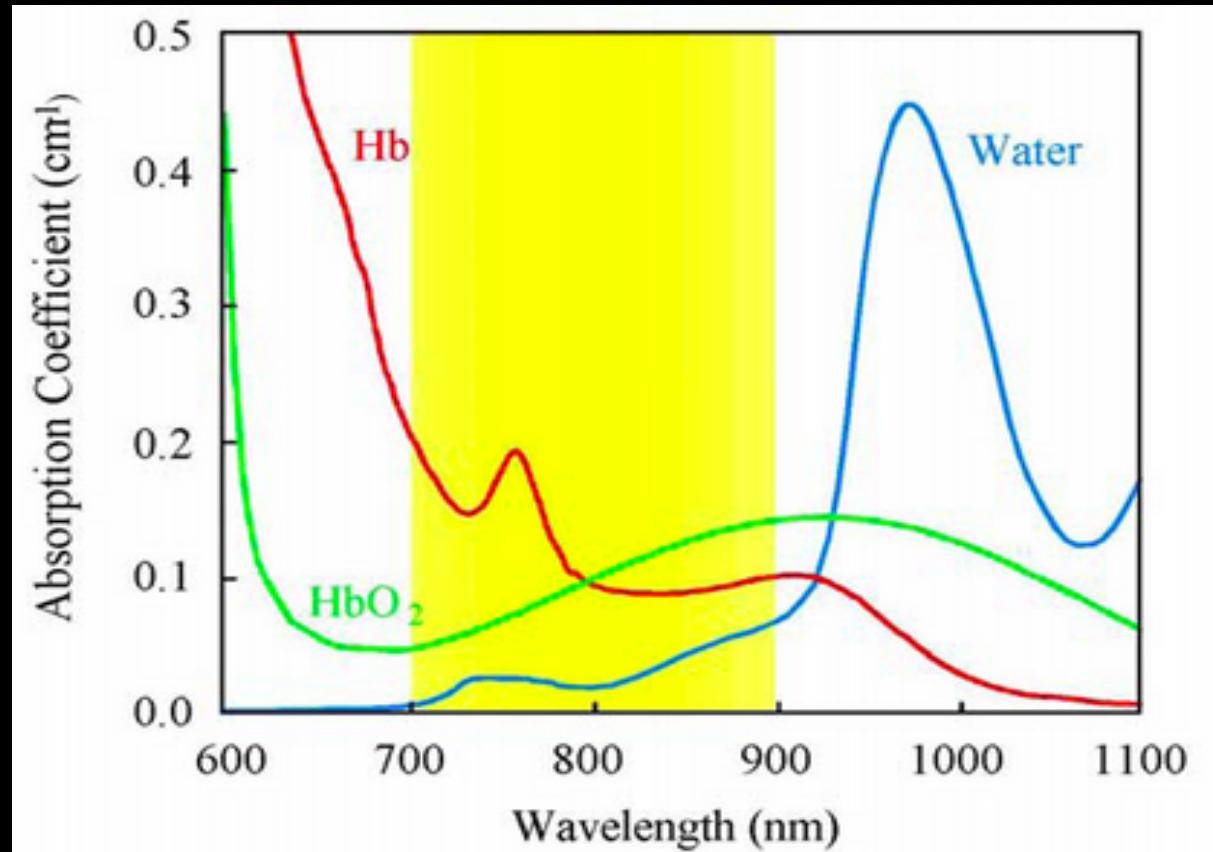
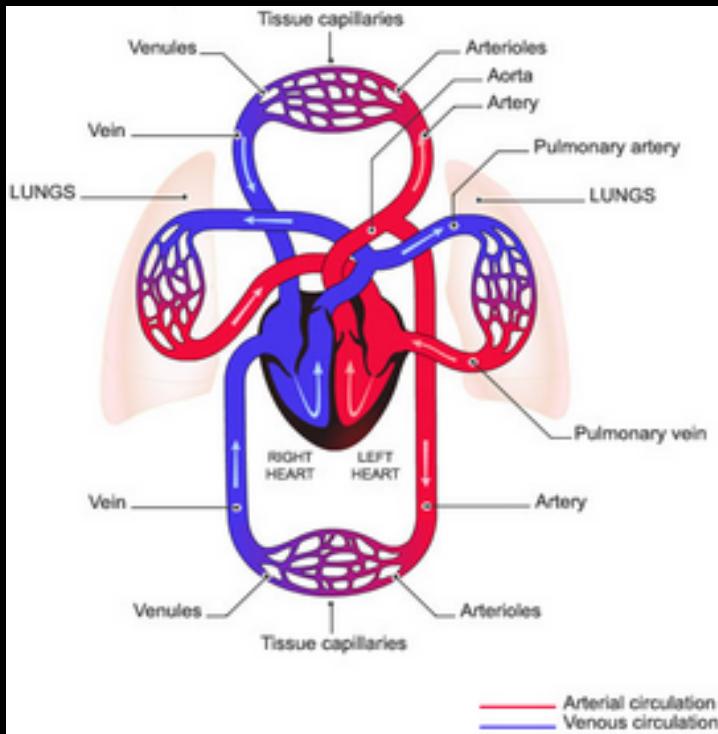
Cerebral oxygenation



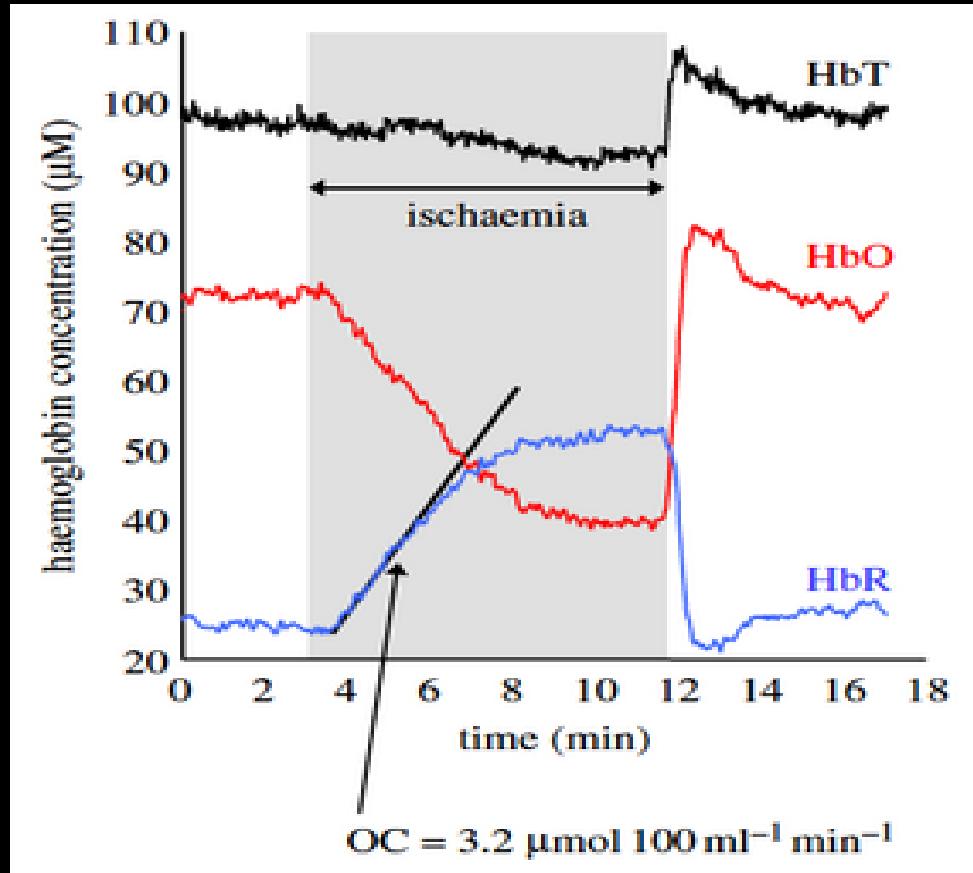
NIRS

Cerebral oxygenation

visible: 380-750nm

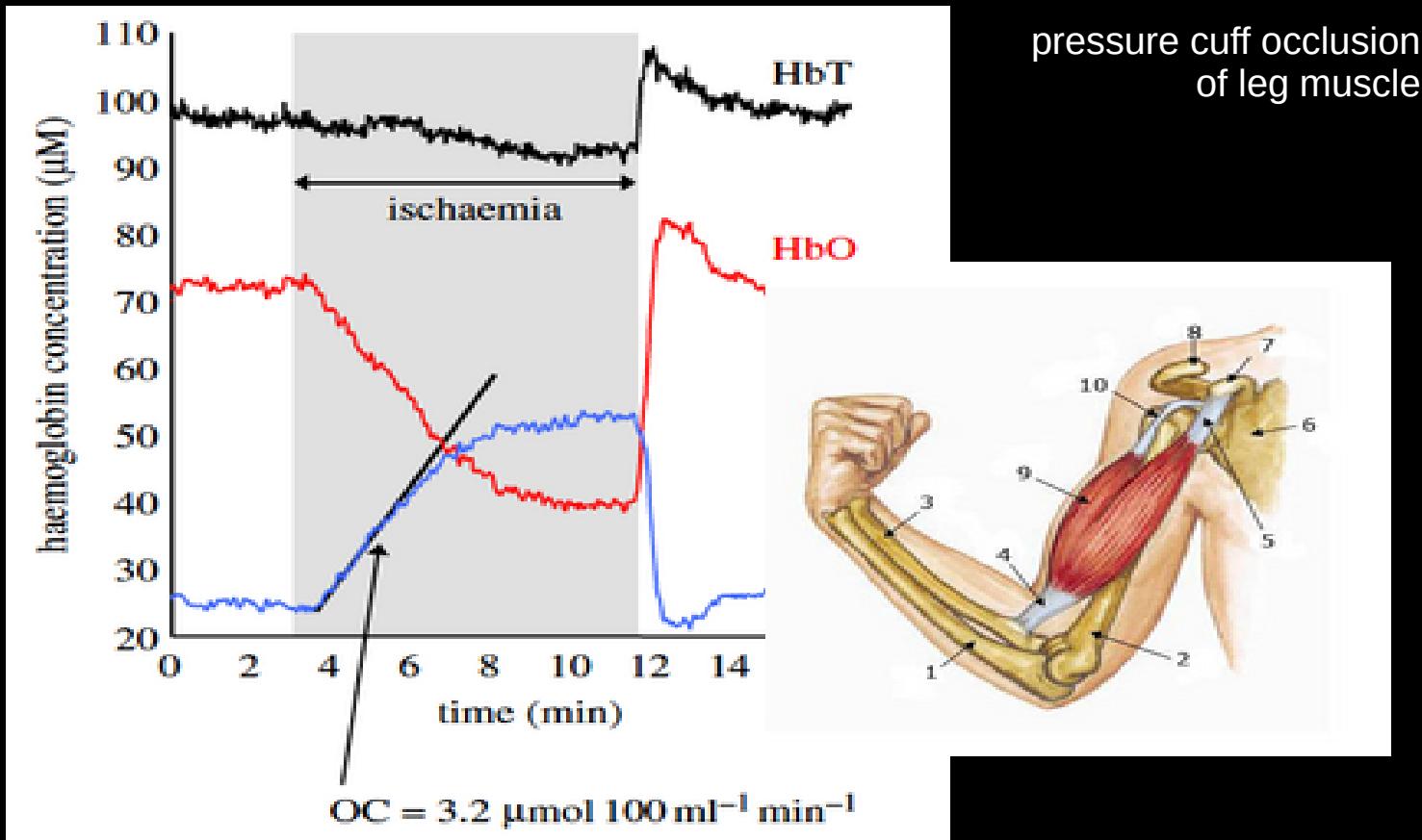


Near Infrared Spectroscopy

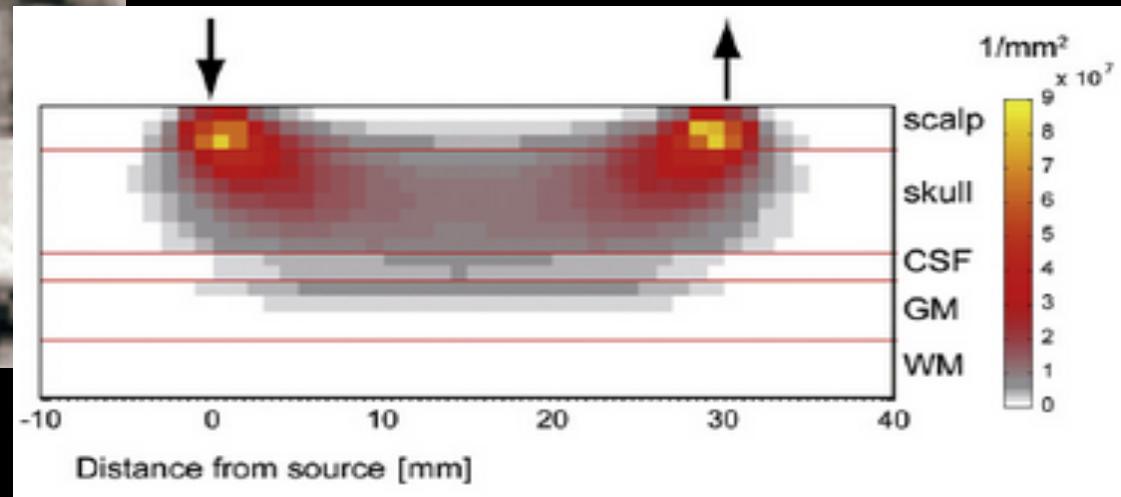
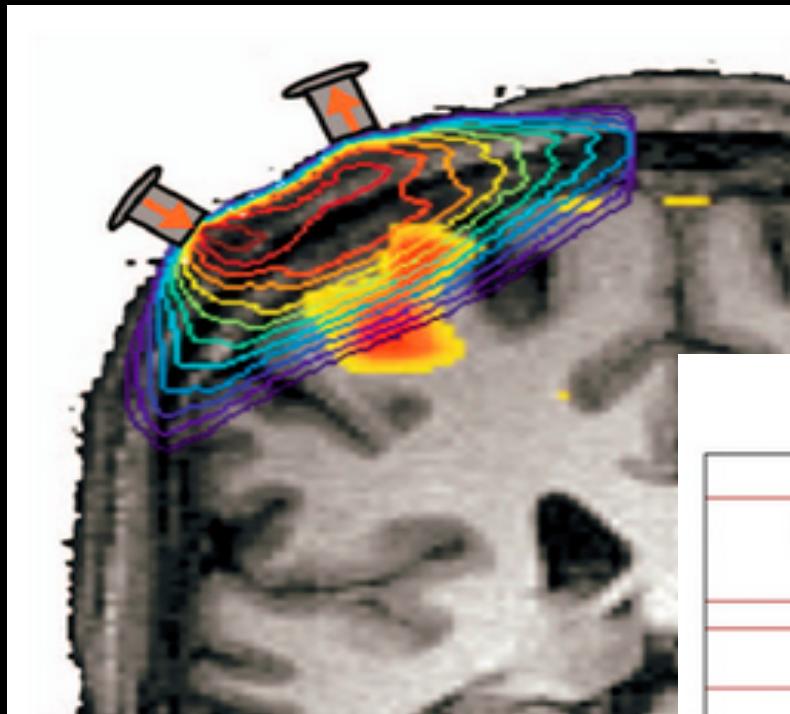


pressure cuff occlusion
of leg muscle

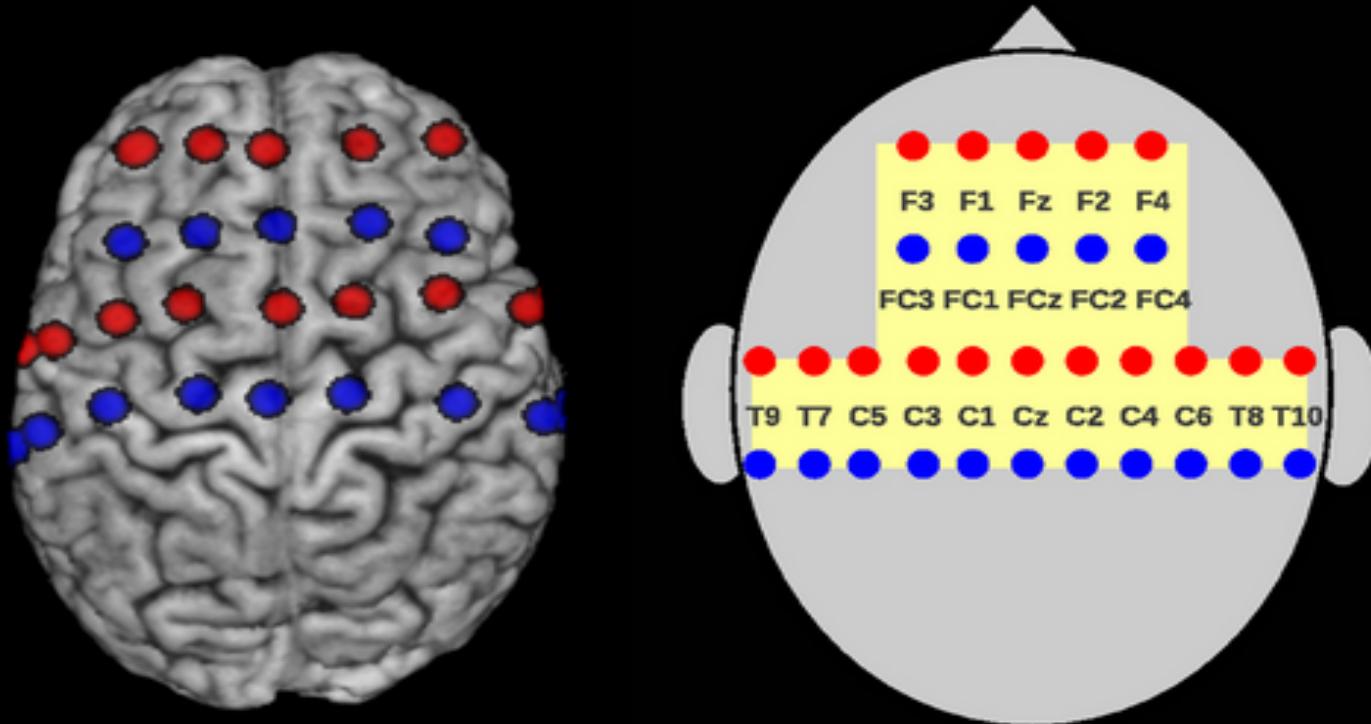
Near Infrared Spectroscopy



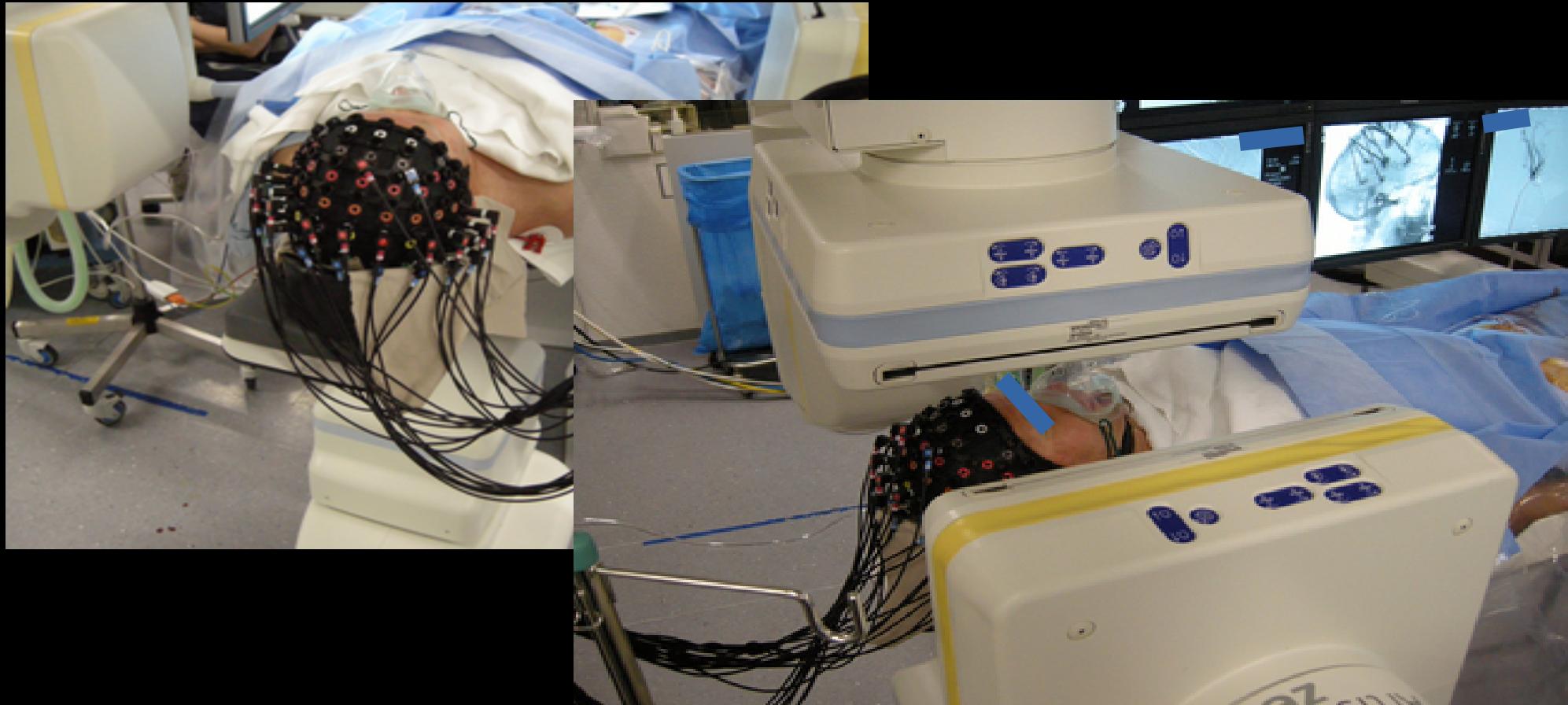
Near Infrared Spectroscopy



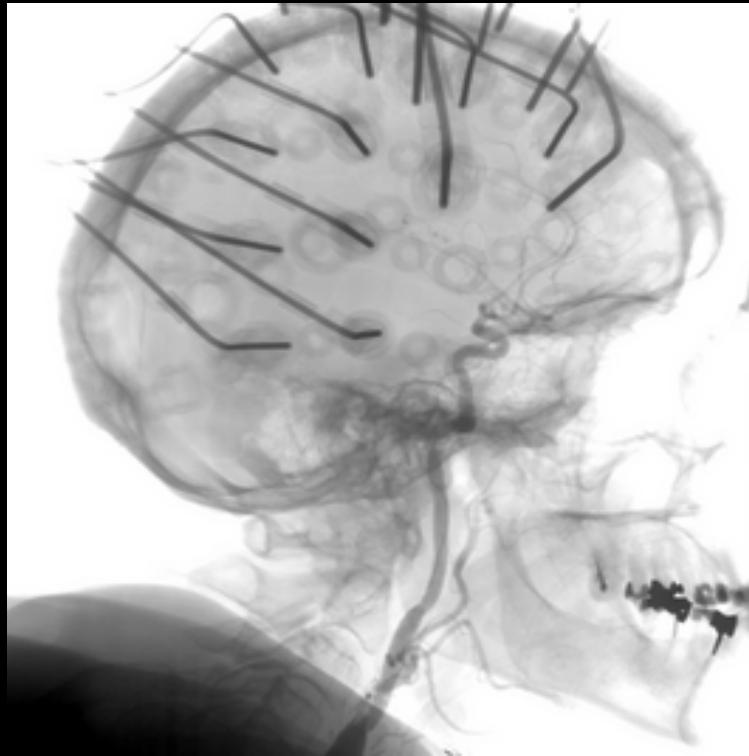
Cerebral oxygenation



Monitoring endovascular neuro-intervention



Monitoring endovascular neuro-intervention

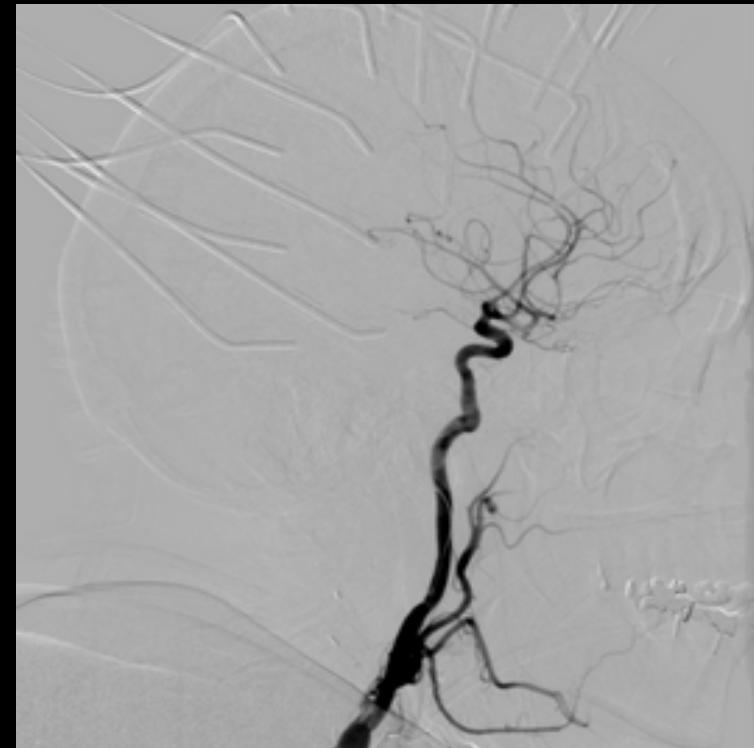


angiography

Monitoring endovascular neuro-intervention

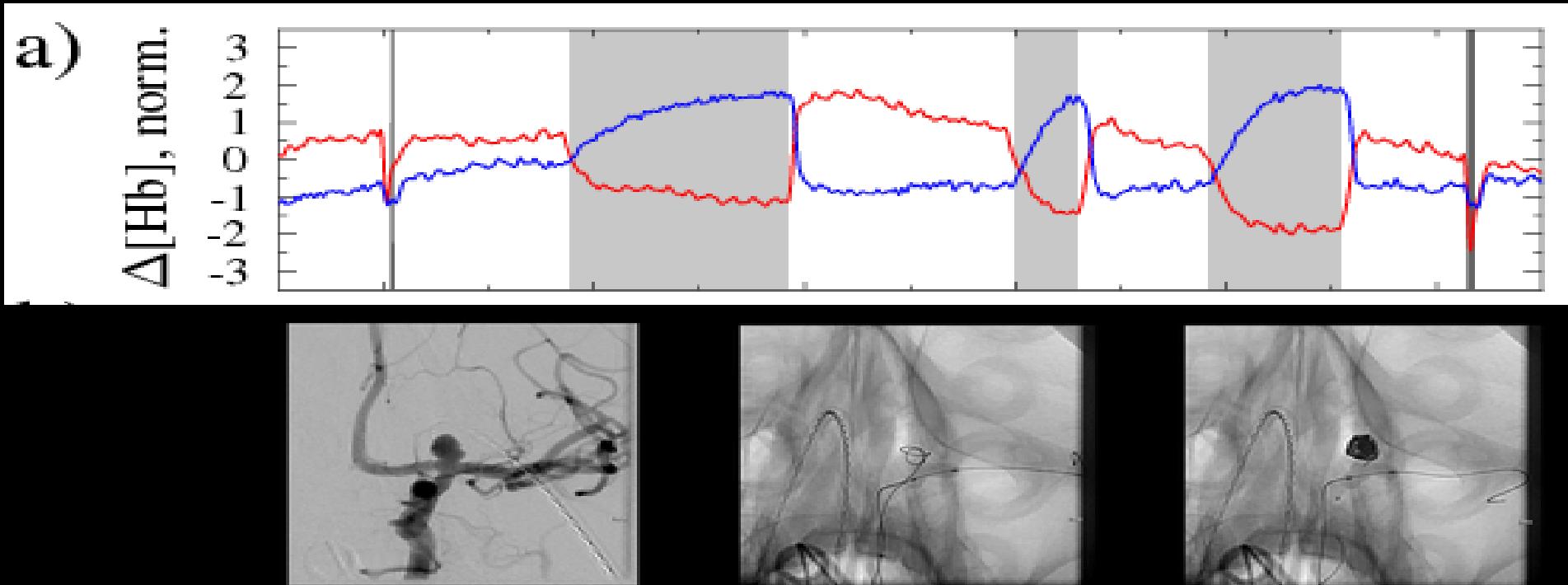


angiography



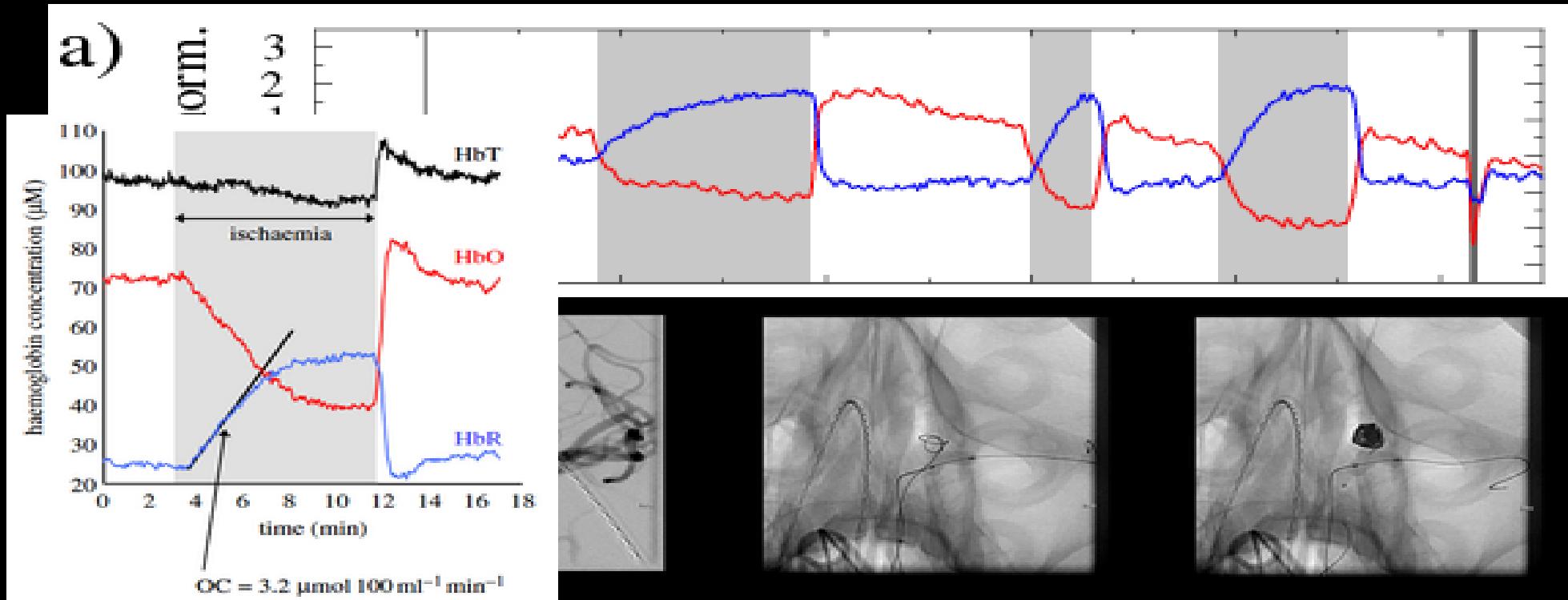
digital subtraction
angiography (DSA)

Monitoring endovascular neuro-intervention



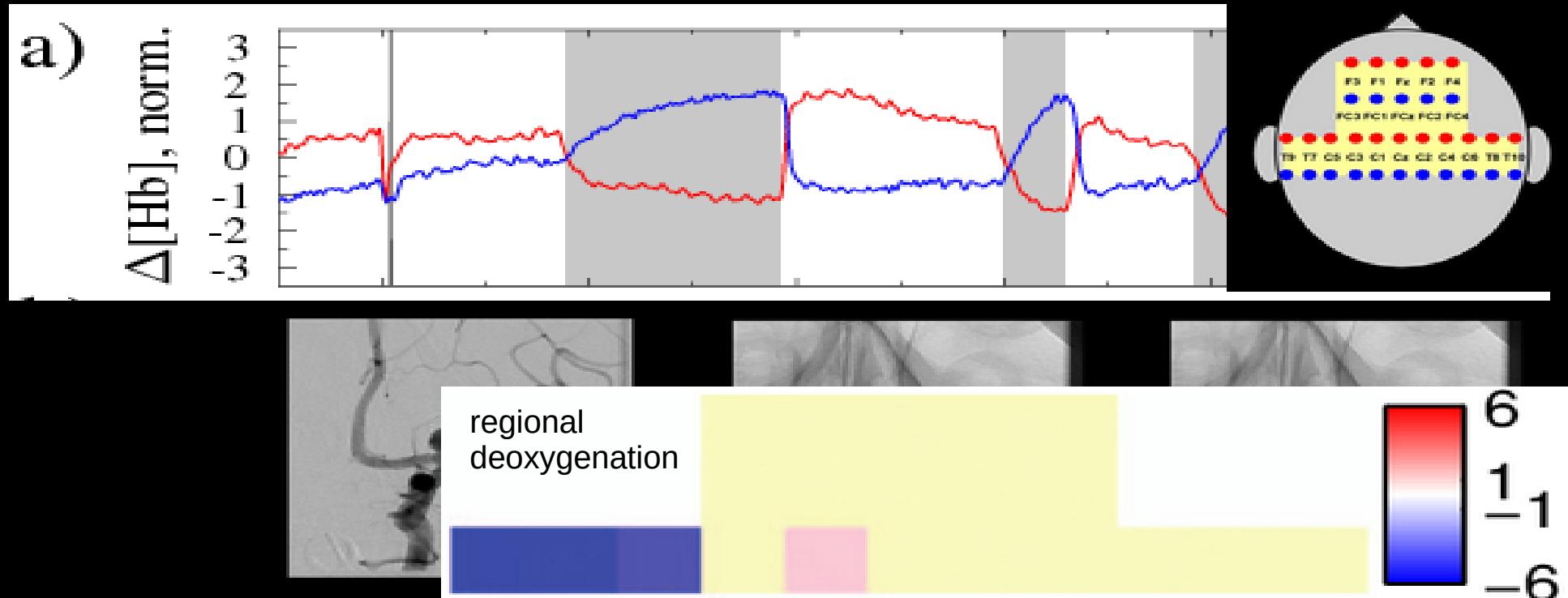
coiling aneurysm in terminal ICA
“balloon remodeling”

Monitoring endovascular neuro-intervention

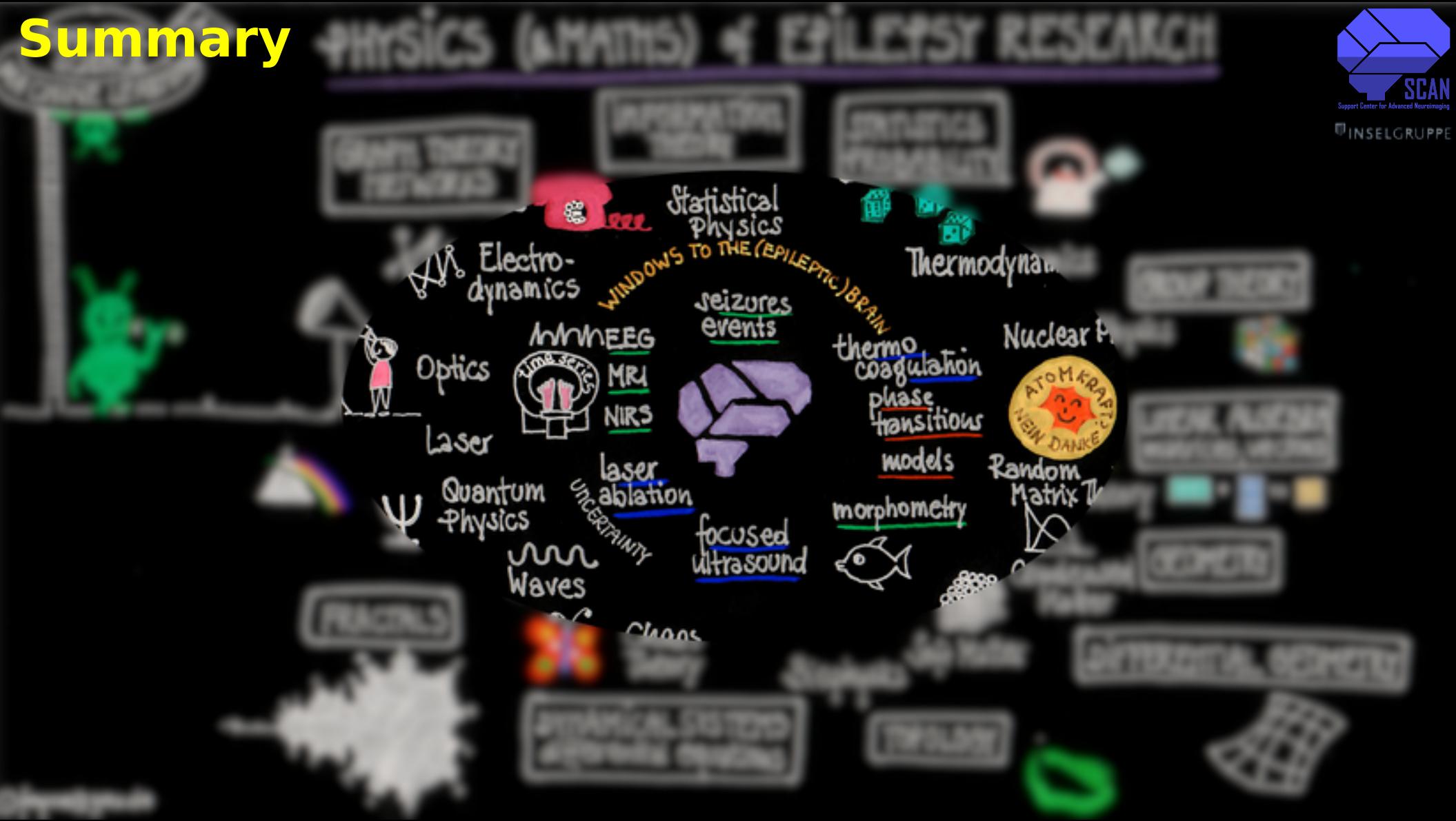


coiling aneurysm in terminal ICA
“balloon remodeling”

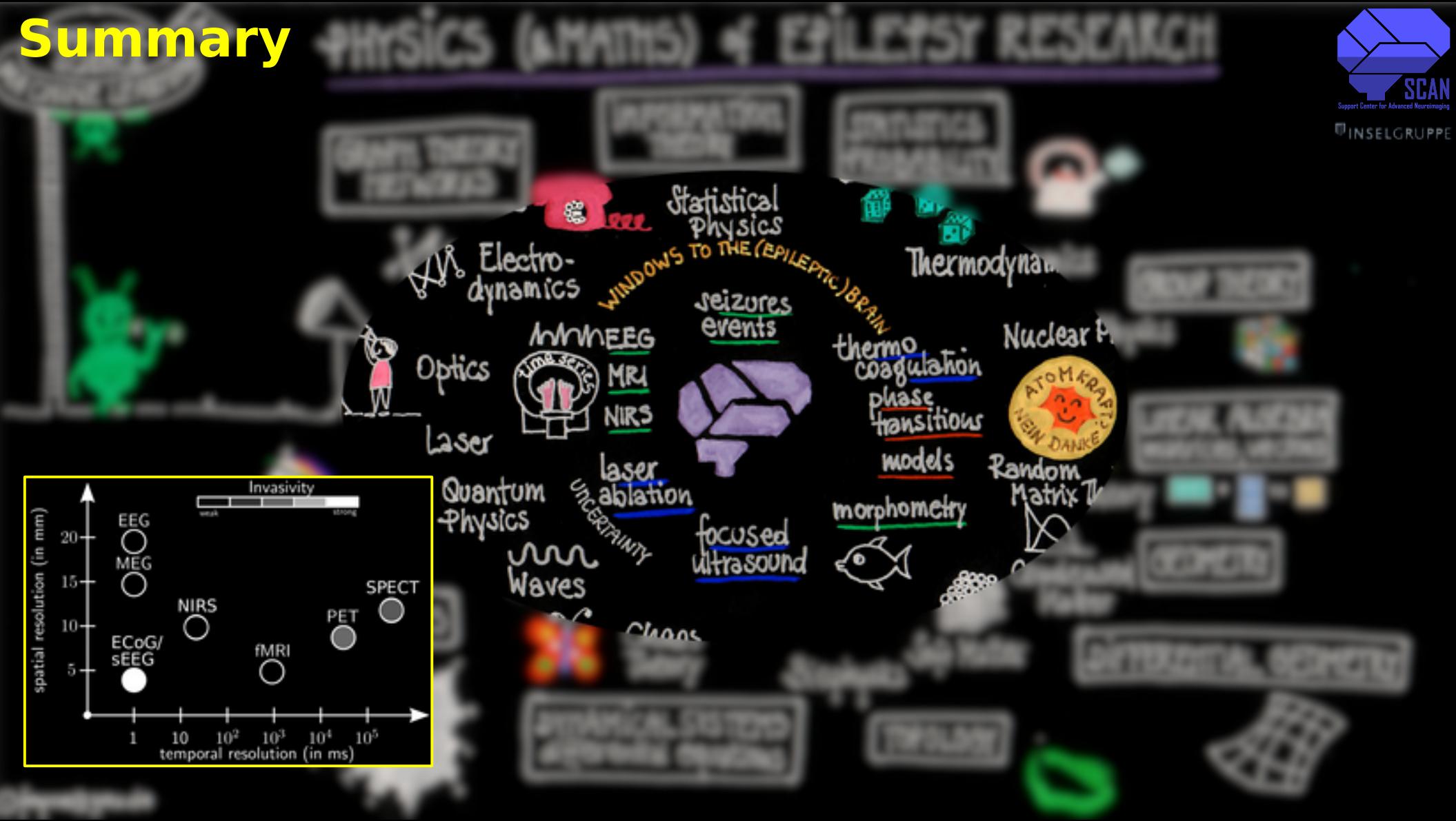
Monitoring endovascular neuro-intervention



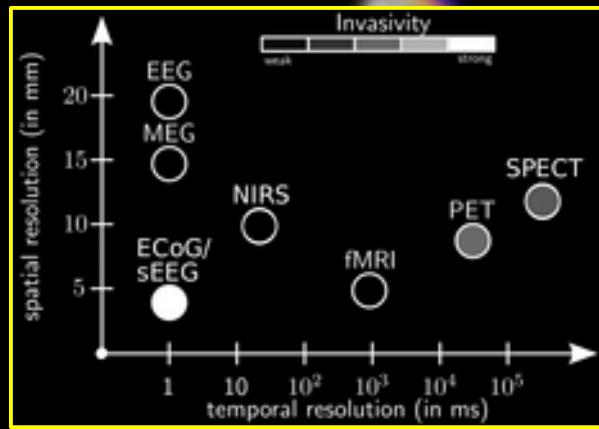
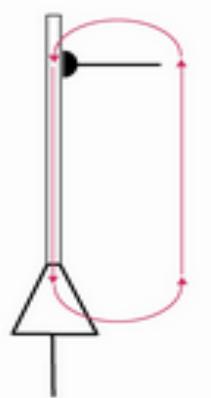
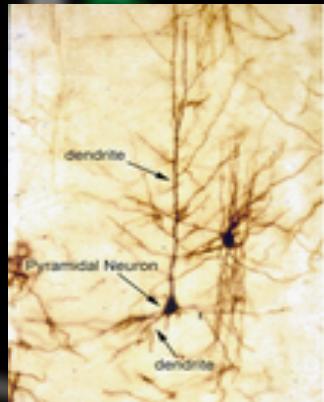
coiling aneurysm in terminal ICA
“balloon remodeling”



Summary

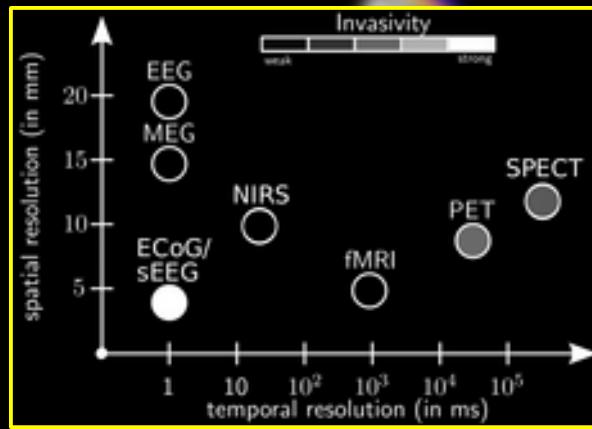
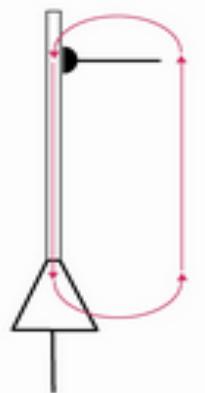
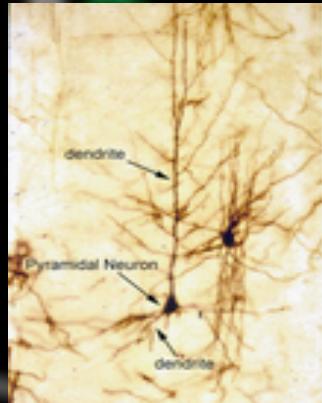


Summary



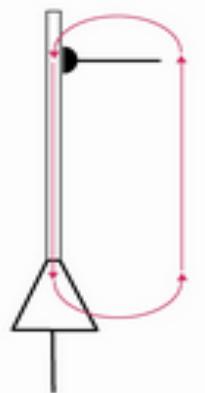
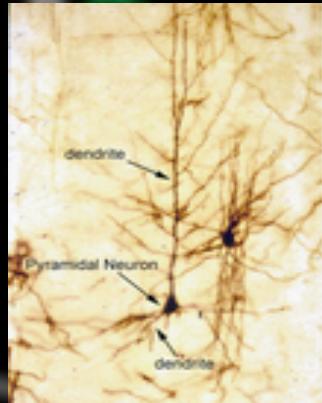
Summary

PHYSICS (& MATHS) OF EPILEPSY RESEARCH



Summary

PHYSICS (& MATHS) OF EPILEPSY RESEARCH



Last word about calculus and programming

$$\cancel{m_1^2 v_1'^2} + 2m_1 m_2 v_1' v_2' + m_2^2 v_2'^2 = -14$$

$$\cancel{m_1^2 v_1'^2} + m_1 m_2 v_2'^2$$

divide by $2m_1 m_2 v_2'$:

$$v_1' = \frac{m_1 - m_2}{2m_1} v_2' \quad (*)$$

plug (*) into (A):

$$m_1 v_1 = \left(\frac{m_1 - m_2}{2} + m_2 \right) v_2' = \frac{m_1 + m_2}{2} v_2'$$

$$v_2' = \frac{2m_1}{m_1 + m_2} \cdot v_1 \quad \text{always } > 0$$

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2} \cdot v_2 \quad \text{can be neg.}$$

these are necessary **tools**
and helpful **aids**
but not the essence!

```
In [4]: 1 def plot_position_vs_time(m1, m2, v1_ini):
2     """
3         reusable function to plot position of both objects as a function of time
4     """
5     fig, ax = plt.subplots(1, 1)
6
7     ax.plot(t_neg, v1_ini * t_neg, linestyle='-', color='b', label="object 1")
8     ax.plot(t_pos, v1_fin(m1, m2, v1_ini) * t_pos, linestyle='-', color='b')
9
10    ax.plot(t_neg, np.zeros(t_neg.shape), linestyle='--', color='r', label="object 2")
11    ax.plot(t_pos, v2_fin(m1, m2, v1_ini) * t_pos, linestyle='--', color='r')
12
13    ax.set_title("central collision with masses: m1 = {0:.3f} * m2".format(m1/m2))
14    ax.set_xlabel('time [s]')
15    ax.set_ylabel('position [m]')
16    ax.legend()
```

equal masses: $m_1 = m_2$

The hitting object 1 comes to rest $v1_fin = 0$ at $t > 0$ and the resting object moves on with velocity $v2_fin = v1_ini$. We choose $m1 = m2 = 1$, and $v1_ini = 1$, and plot both positions as a function of time:

```
In [5]: 1 t_neg = np.linspace(-3., 0., 31)
2 t_pos = np.linspace(0., 3., 31)
3
4 m1 = 1.
5 m2 = 1.
6 v1_ini = 1.
7
8 plot_position_vs_time(m1, m2, v1_ini)
9
```