

# Nanomagnetism and neurology: a short story

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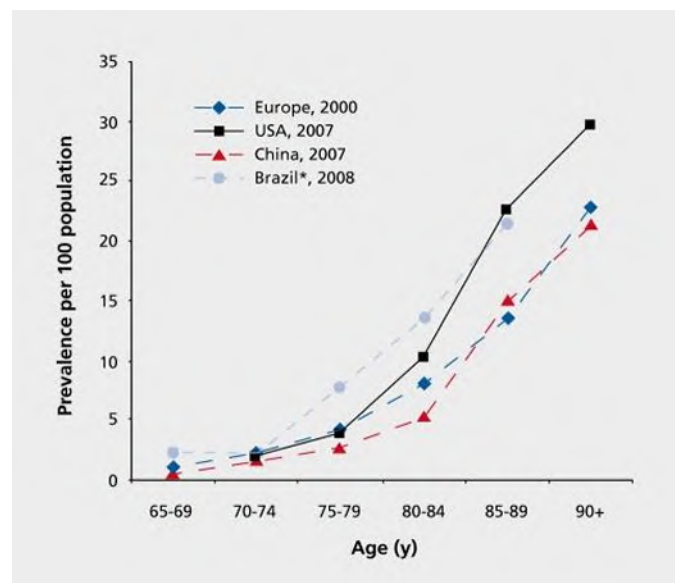
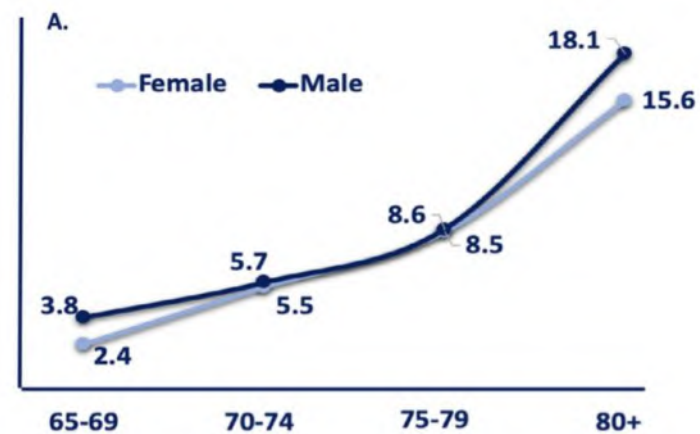
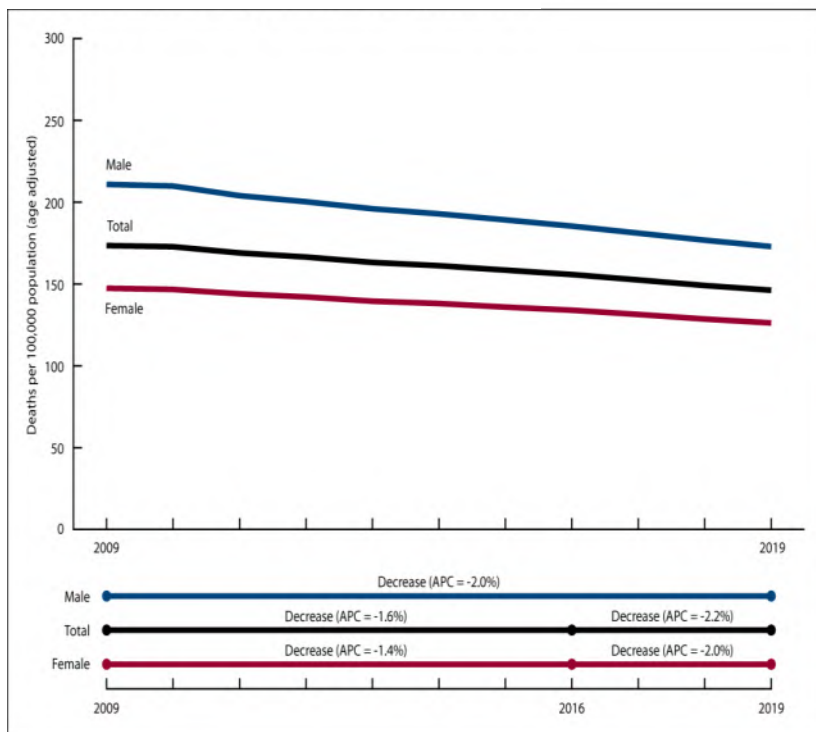




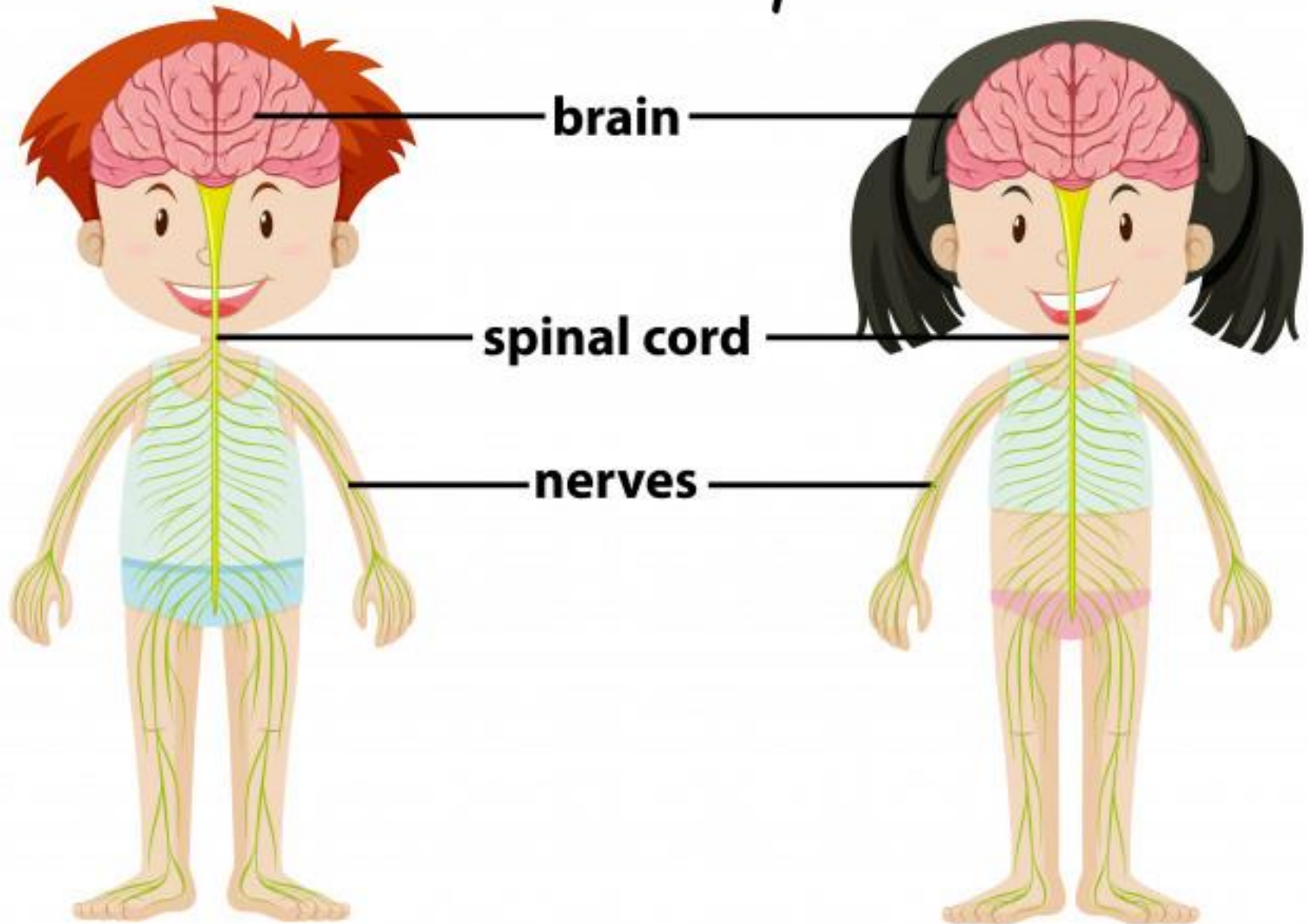
Nanomagnetism division

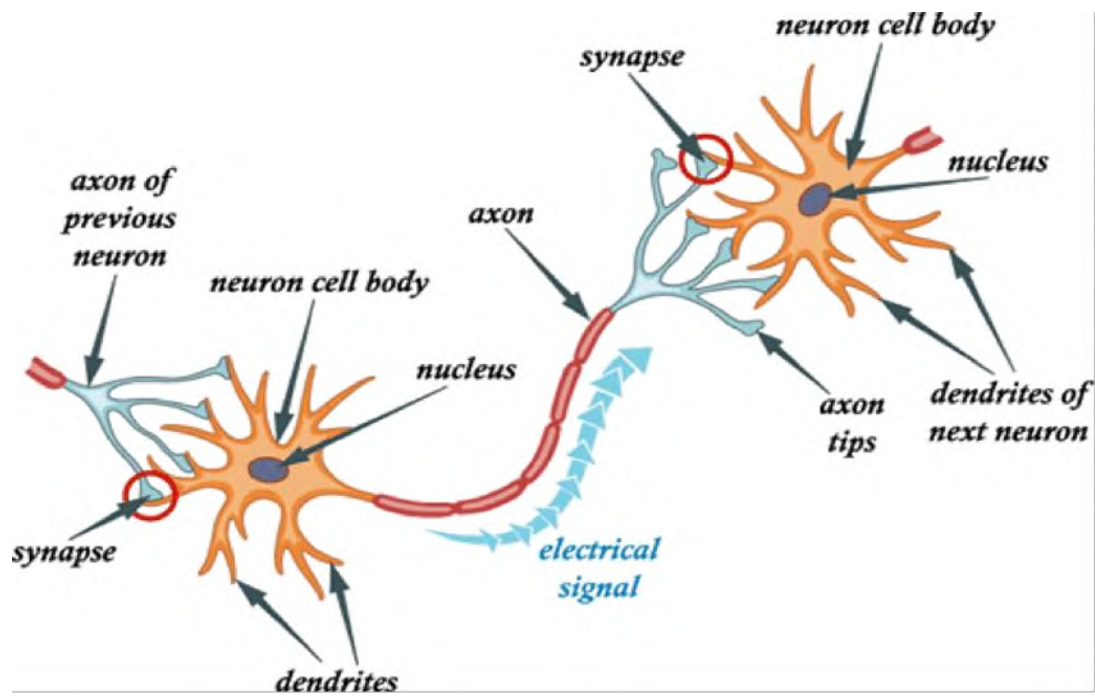
Neural interfaces lab.  
Nanodevices for biomedical technology

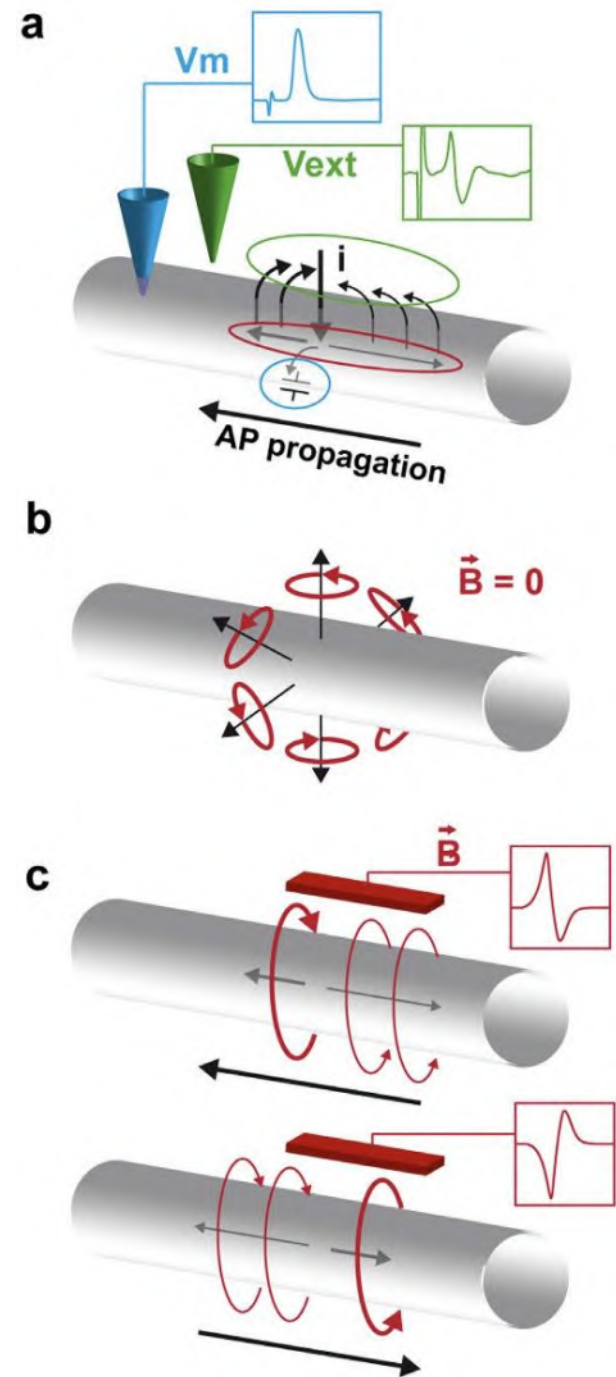
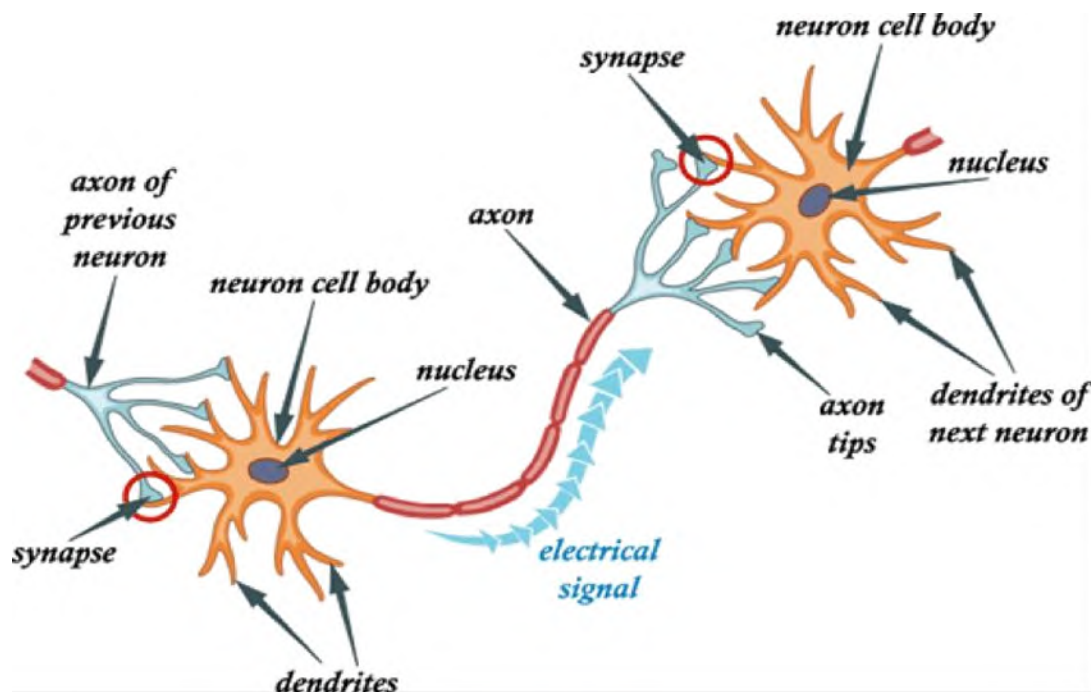




# Nervous System







# SCIENTIFIC REPORTS

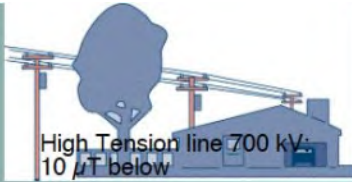
OPEN

## Local recording of biological magnetic fields using Giant Magneto Resistance-based micro-probes

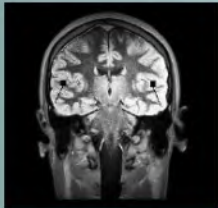
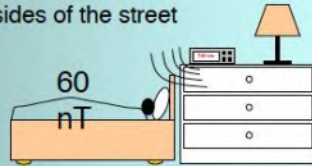
Received: 17 August 2016  
Accepted: 18 November 2016  
Published: 19 December 2016

Francesca Barbieri<sup>1,2</sup>, Vincent Trauchessec<sup>3</sup>, Laure Caruso<sup>3</sup>, Josué Trejo-Rosillo<sup>3</sup>, Bartosz Telenczuk<sup>1,4</sup>, Elodie Paul<sup>1</sup>, Thierry Bal<sup>1</sup>, Alain Destexhe<sup>1,4</sup>, Claude Fermon<sup>1</sup>, Myriam Pannetier-Lecoeur<sup>3</sup> & Gilles Ouanounou<sup>1</sup>





$0.1\text{--}1\ \mu\text{T}$  in both sides of the street



fT

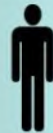
pT

nT

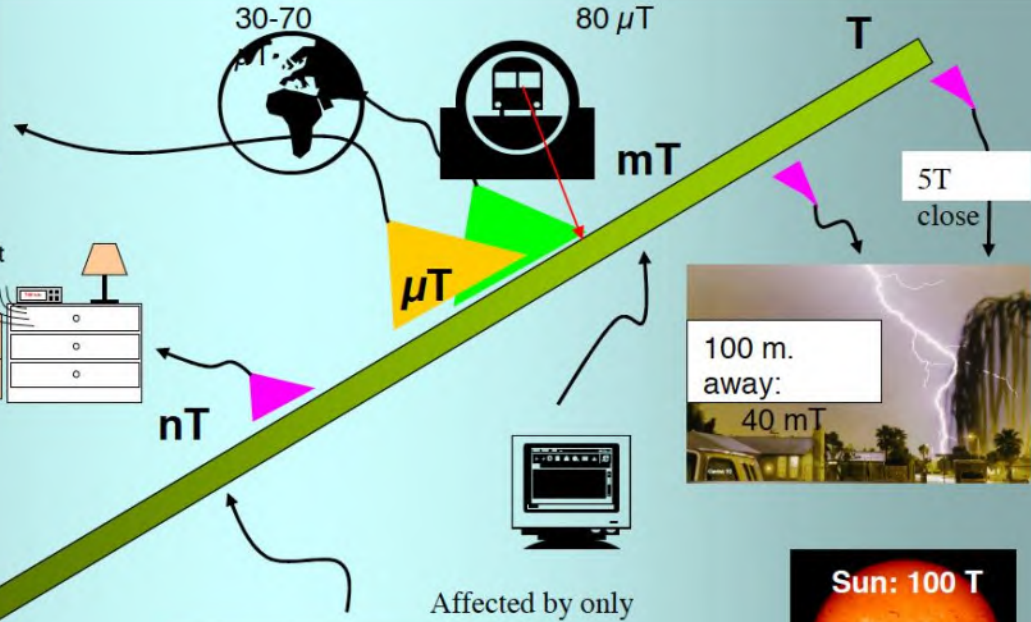
$\mu\text{T}$

mT

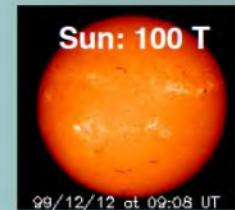
T



Human magnetic  
field



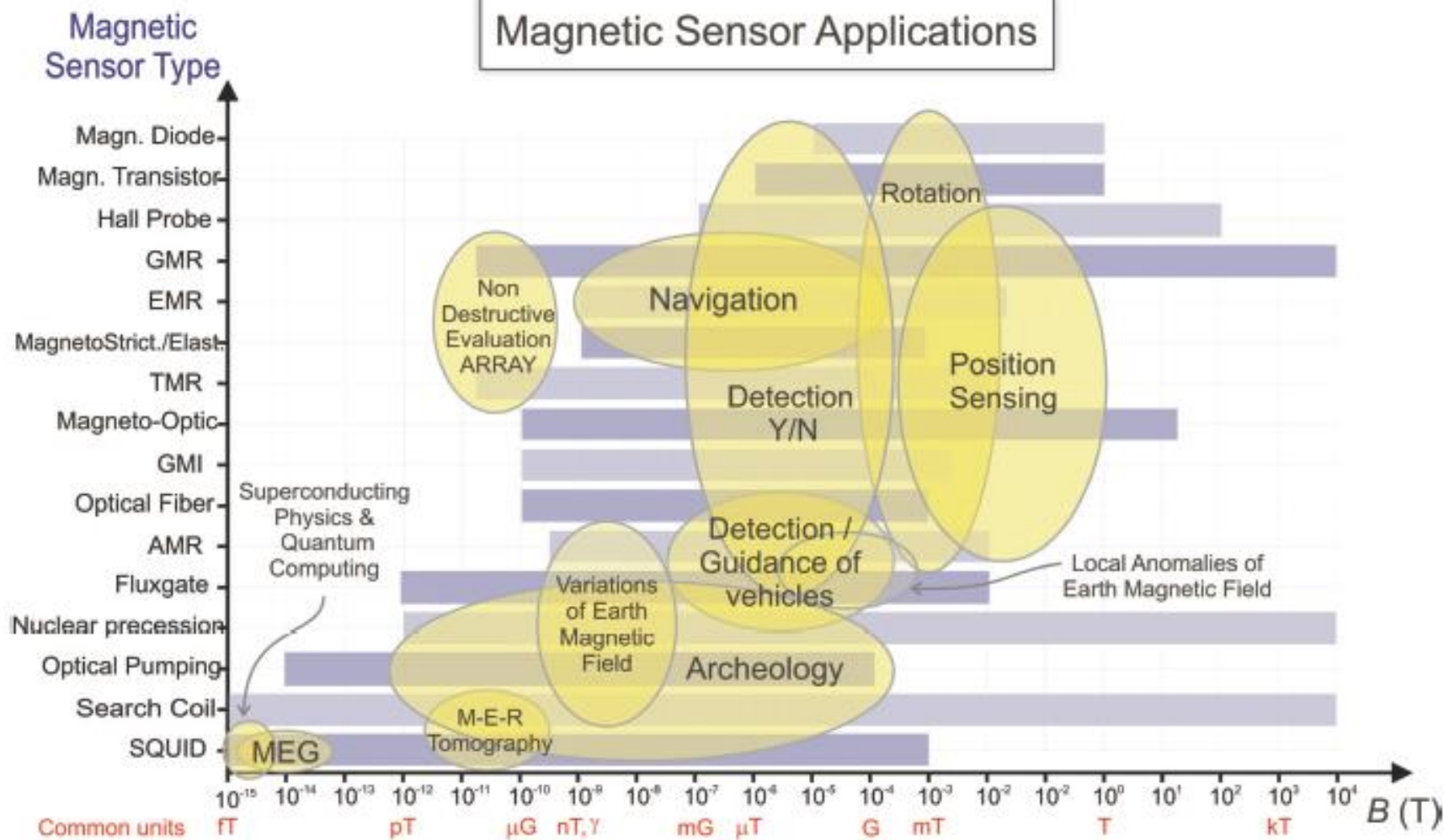
Submarine



Pulsar:  $10^8\ \text{T}$



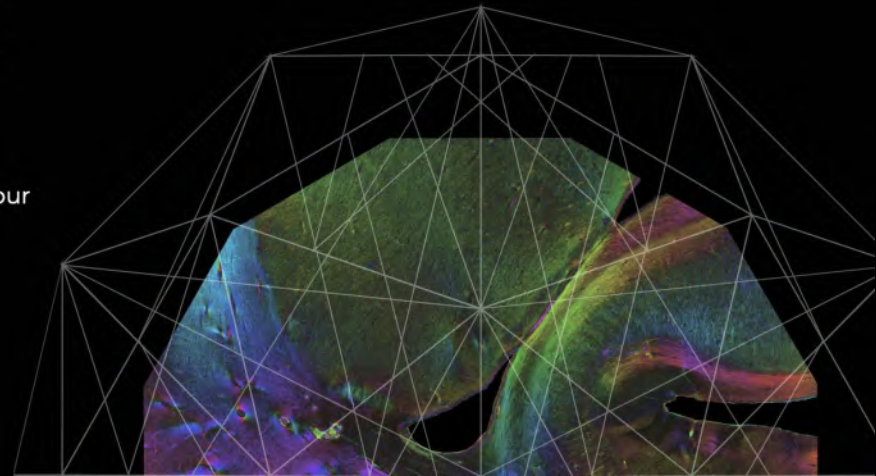
# Magnetic Sensor Applications



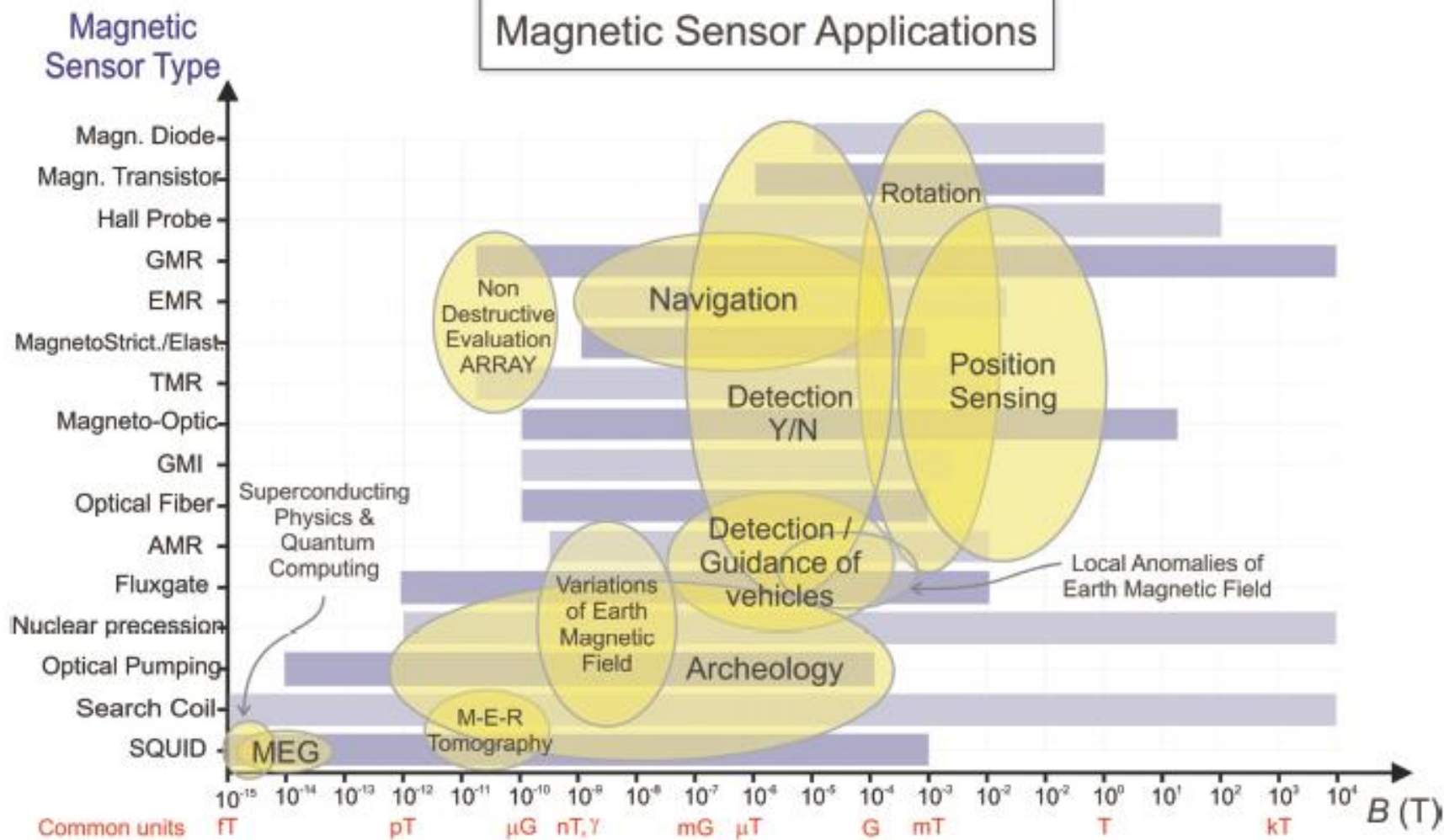
# Welcome to the Human Brain Project

The Human Brain Project aims to put in place a cutting-edge research infrastructure that will allow scientific and industrial researchers to advance our knowledge in the fields of neuroscience, computing, and brain-related medicine

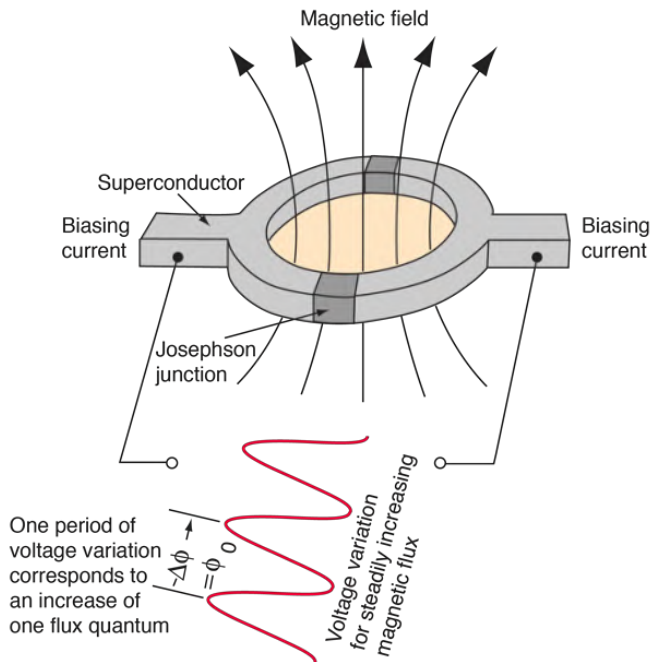
Section of nerve fibres in the hippocampus of the brain visualised using 3D Polarised Light Imaging.



# Magnetic Sensor Applications



# Magnetoencephalography



Magnetoencephalography – needs for cryogenics  
Clinical applications – bulky devices  
Too sensitive – need for screening



# Why MEG?

fMRI is used to localize brain functions prior to surgery. This offers an indirect measure of brain activity with poor temporal resolution.

Long-term monitoring by EEG requires large numbers of electrodes to be consistently positioned on the subject's head. Localization accuracy is poor due to the conduction of the signal through the skull and the scalp.

SPECT is highly invasive. It requires a contrast medium to be injected and the patient to be having an epileptic seizure.

Intracranial EEG is an accurate technique for localizing and confirming epileptic areas. However, it requires brain surgery and has limited spatial coverage and resolution.



MEG is a direct measure of electrophysiological activity within the brain and may therefore more accurately detect actual brain activity.



Greater accuracy of source localization is possible with MEG as the skull and scalp are transparent to the magnetic signals, allowing a consistent, clean signal. Propagation of epileptic activity from one area of the brain to another can be monitored with MEG.

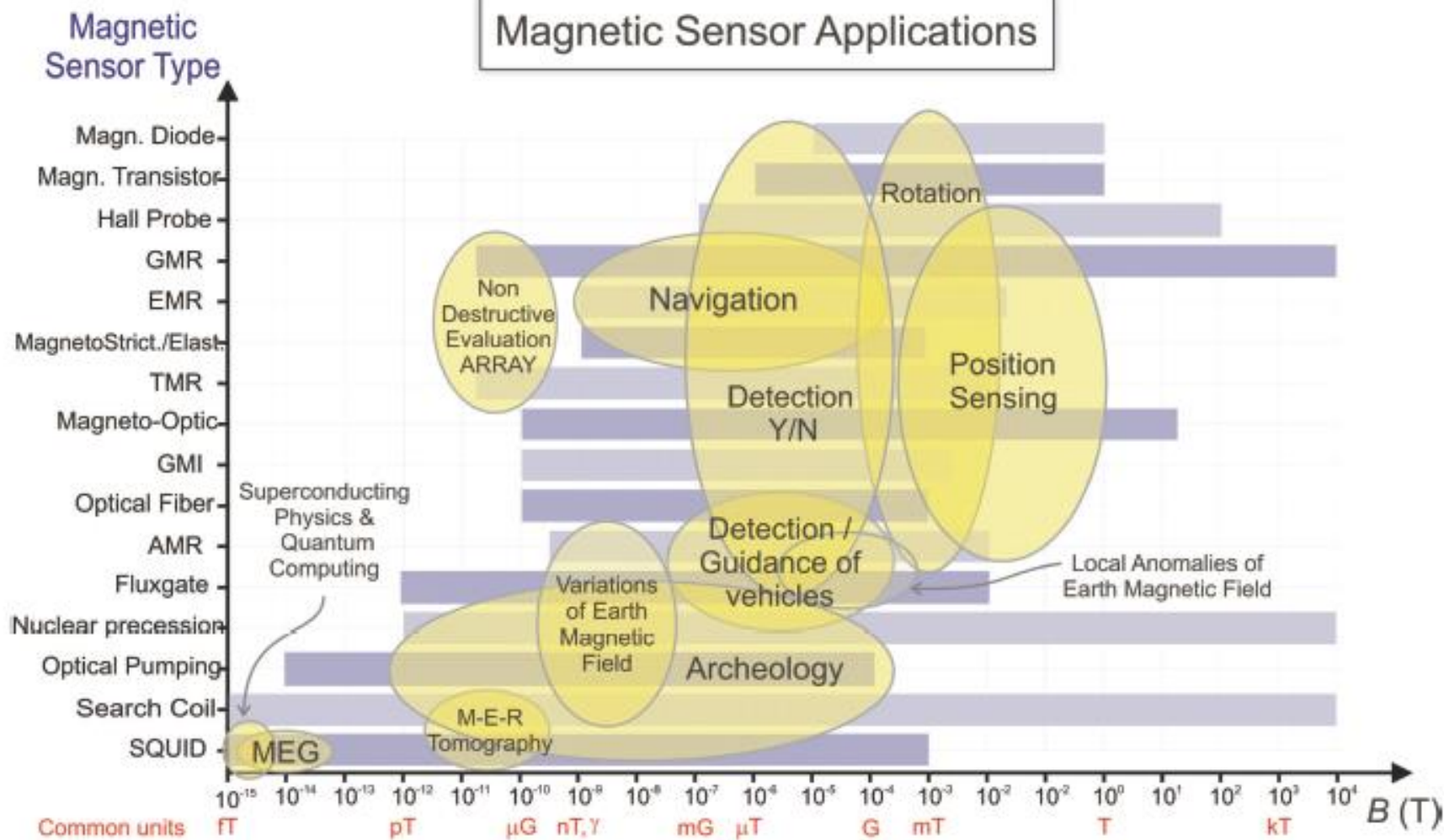


MEG is non-invasive. The patient experience is peaceful and comfortable. There is no need to inject contrast agents or require patients to undergo epileptic seizures. Many patients fall asleep during their MEG scan.

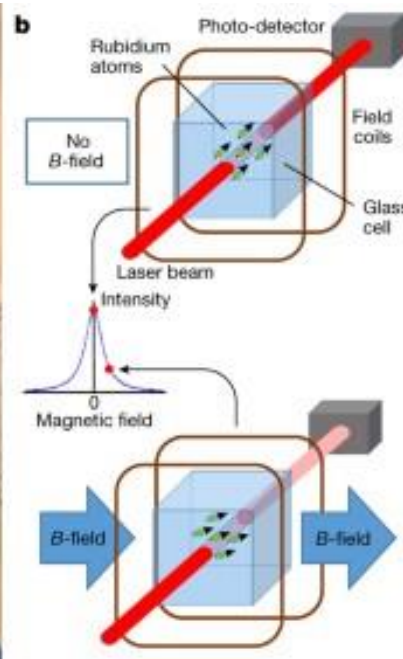


MEG does not require placing invasive electrodes. MEG can be used to monitor most brain areas completely non-invasively.

# Magnetic Sensor Applications

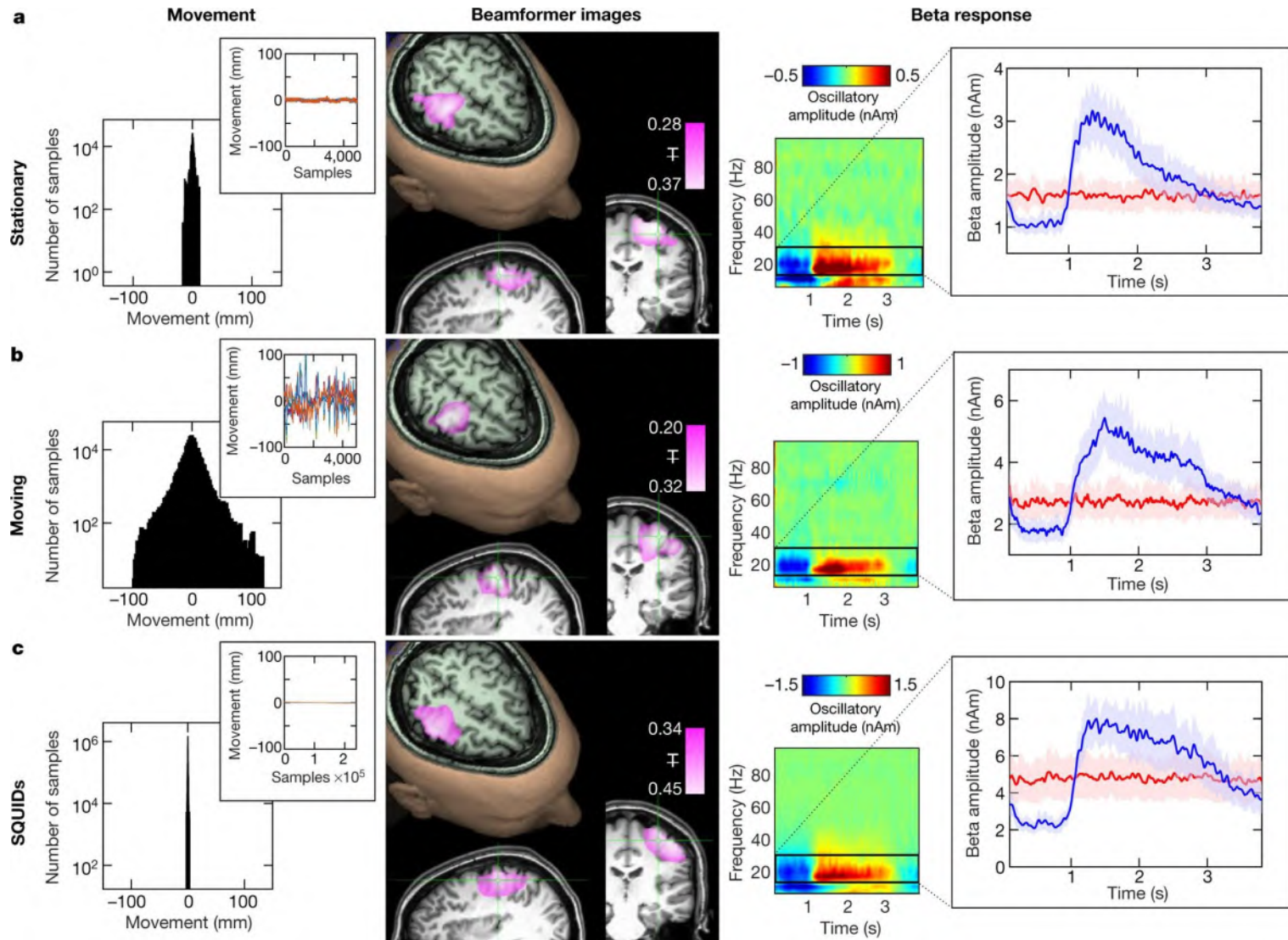


# Optically pumped magnetometers



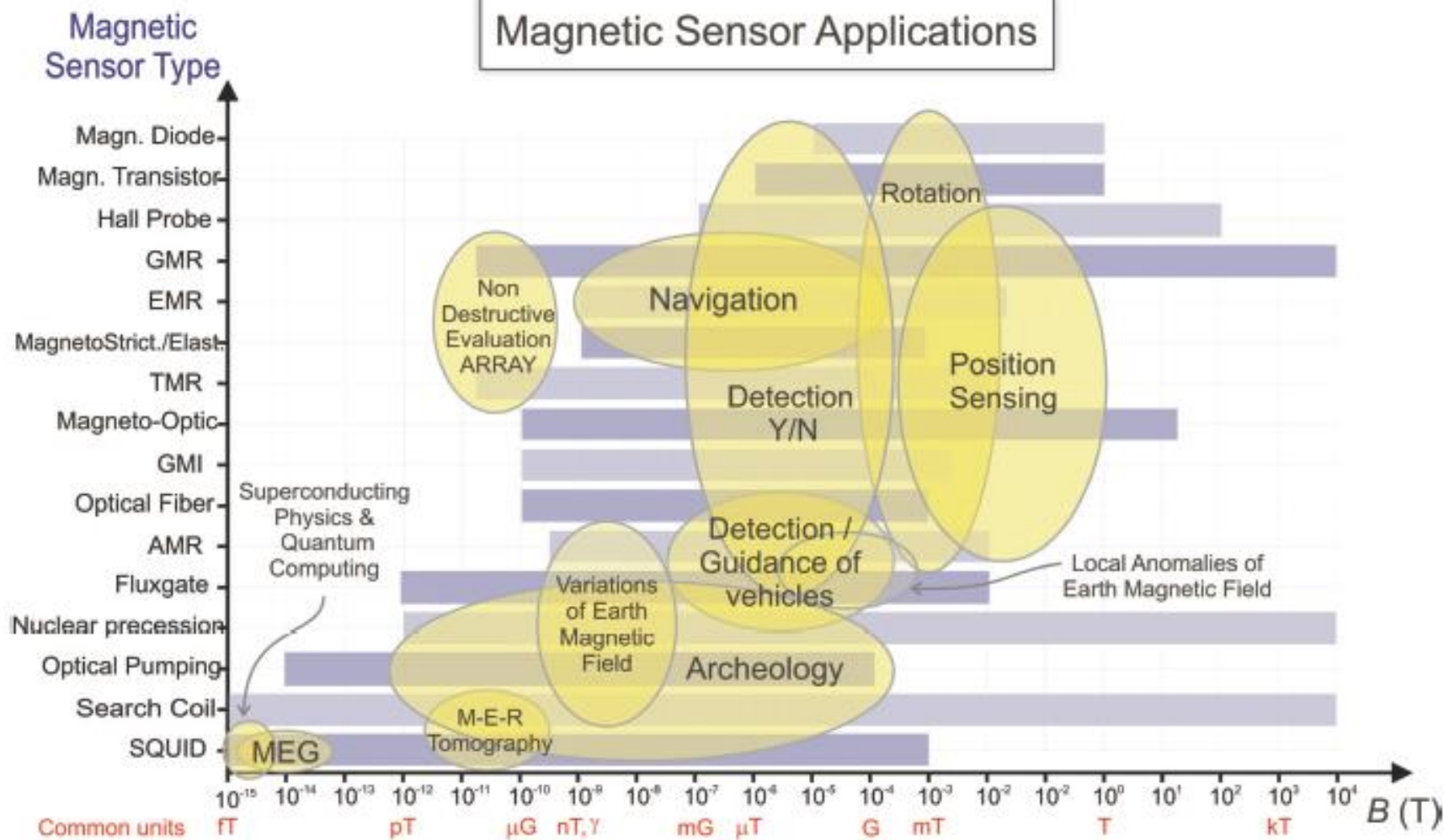


# Optically pumped magnetometers



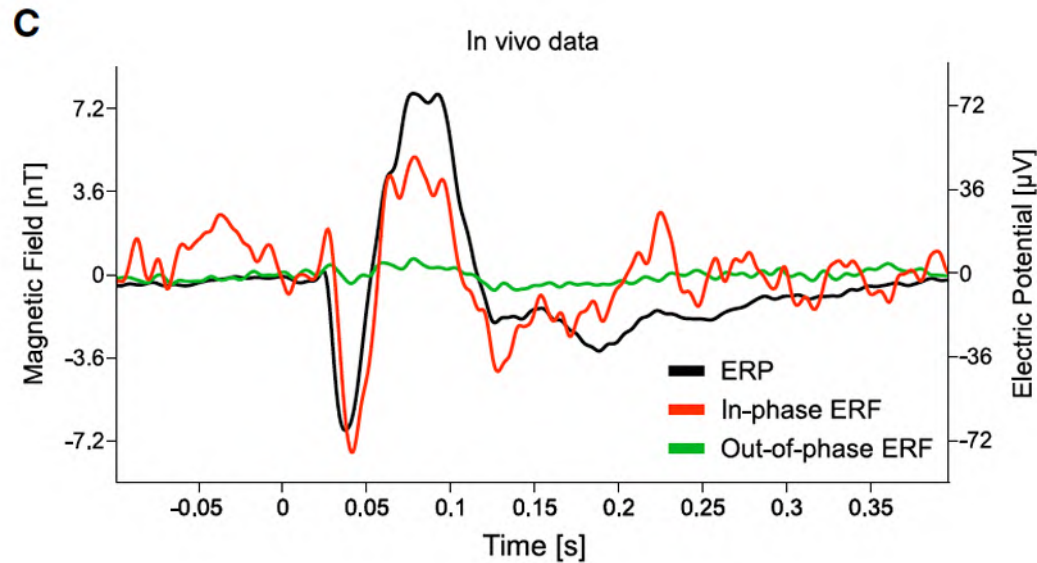
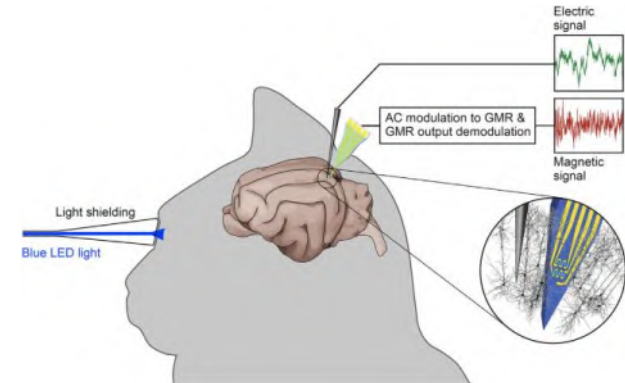
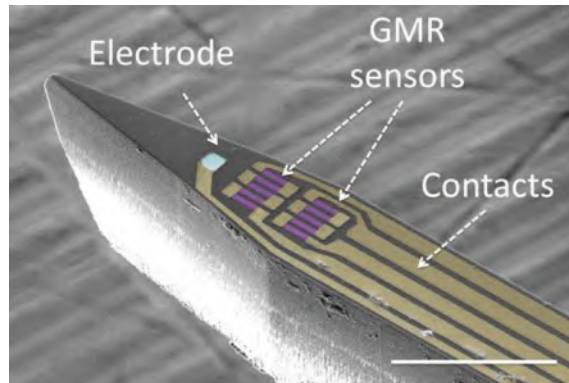


# Magnetic Sensor Applications



# *In Vivo* Magnetic Recording of Neuronal Activity

Laure Caruso,<sup>1</sup> Thomas Wunderle,<sup>2</sup> Christopher Murphy Lewis,<sup>2</sup> Joao Valadeiro,<sup>3,4</sup> Vincent Trauchessec,<sup>1</sup> Josué Trejo Rosillo,<sup>1</sup> José Pedro Amaral,<sup>3,4</sup> Jianguang Ni,<sup>2</sup> Patrick Jendritza,<sup>2</sup> Claude Fermon,<sup>1</sup> Susana Cardoso,<sup>3,4</sup> Paulo Peixeiro Freitas,<sup>3,4</sup> Pascal Fries,<sup>2,5,6,\*</sup> and Myriam Pannetier-Lecoeur<sup>1,6,7,\*</sup>



# The ByAxon Project

*Talking to neurons*

## A pluridisciplinary consortium



Physics /Engineers  
Growth of spintronics materials  
High-sensitivity sensors

Physics / Chemists/ Engineers  
Fabrication of nanoelectrodes  
Low noise electronics  
Integration of final device



Clinicians / Biologists  
In-vitro biocompatibility  
Advice



Neurobiologists  
Electrophysiology  
Ex-vivo final testing



Biologists / Veterinarians  
In-vivo biocompatibility



## ByAxon: a project leded by women



Prof. M. Teresa González



Dr. Laurence Méchin



Dr. Elisa López-Dolado



Prof. Laura Ballerini

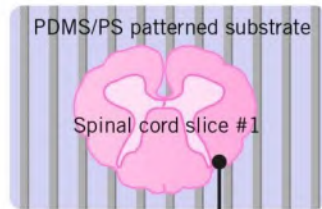


Dr. M. Concepción Serrano

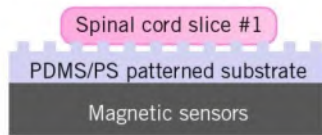


Dr. Bern Lecher

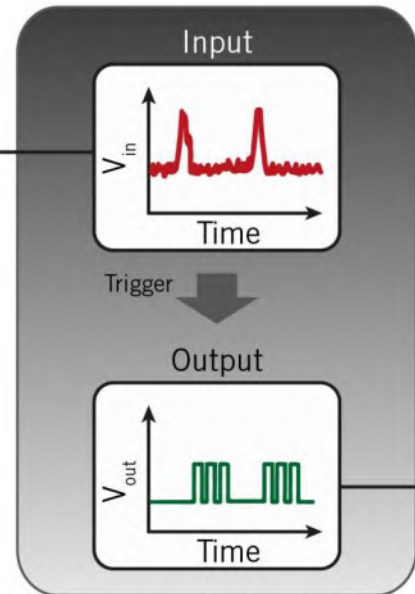
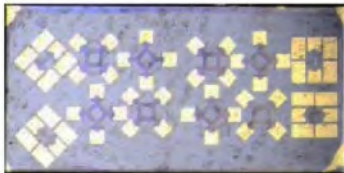
Top view



Side view



Anisotropic magnetoresistance sensors

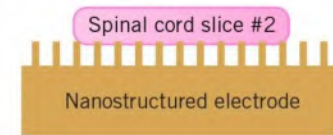


On-top-of-the-table electronics

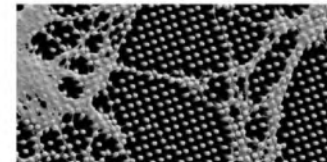
Top view



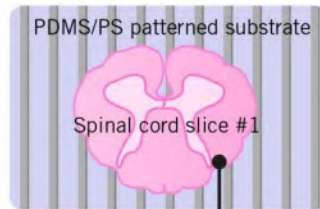
Side view



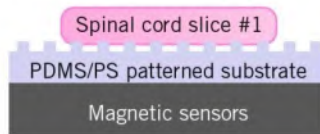
Nanostructured electrodes



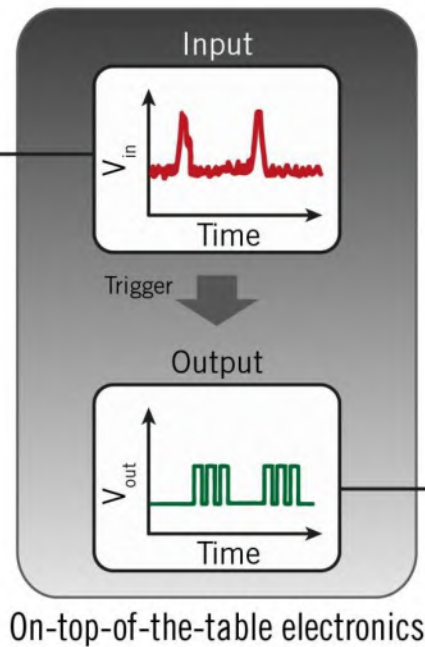
Top view



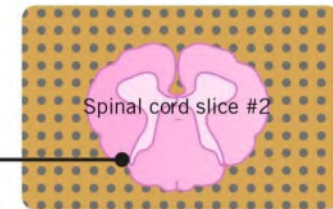
Side view



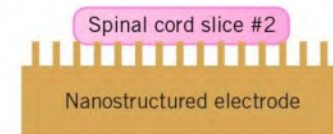
Anisotropic magnetoresistance sensors



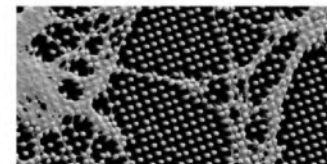
Top view



Side view



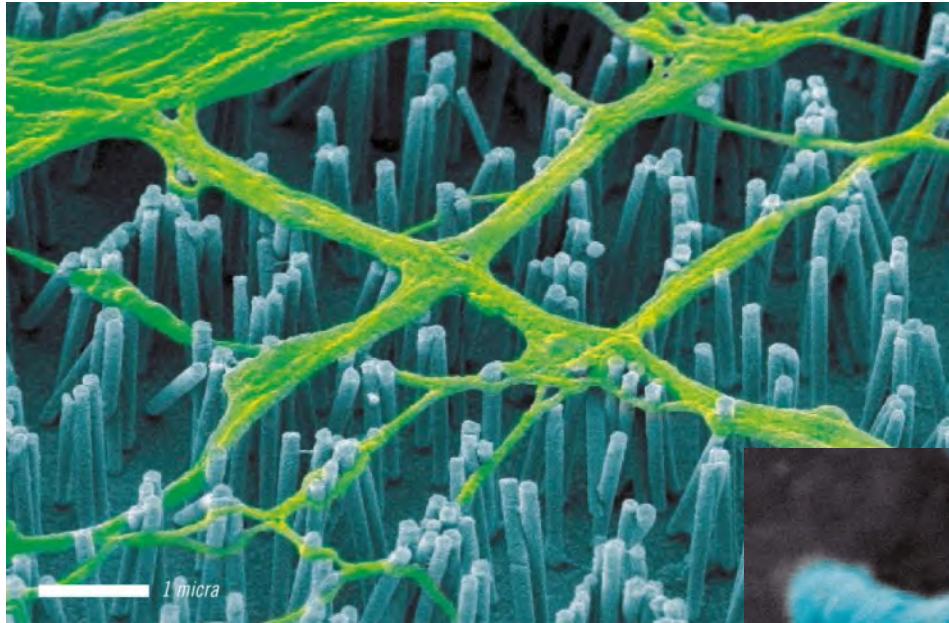
Nanostructured electrodes

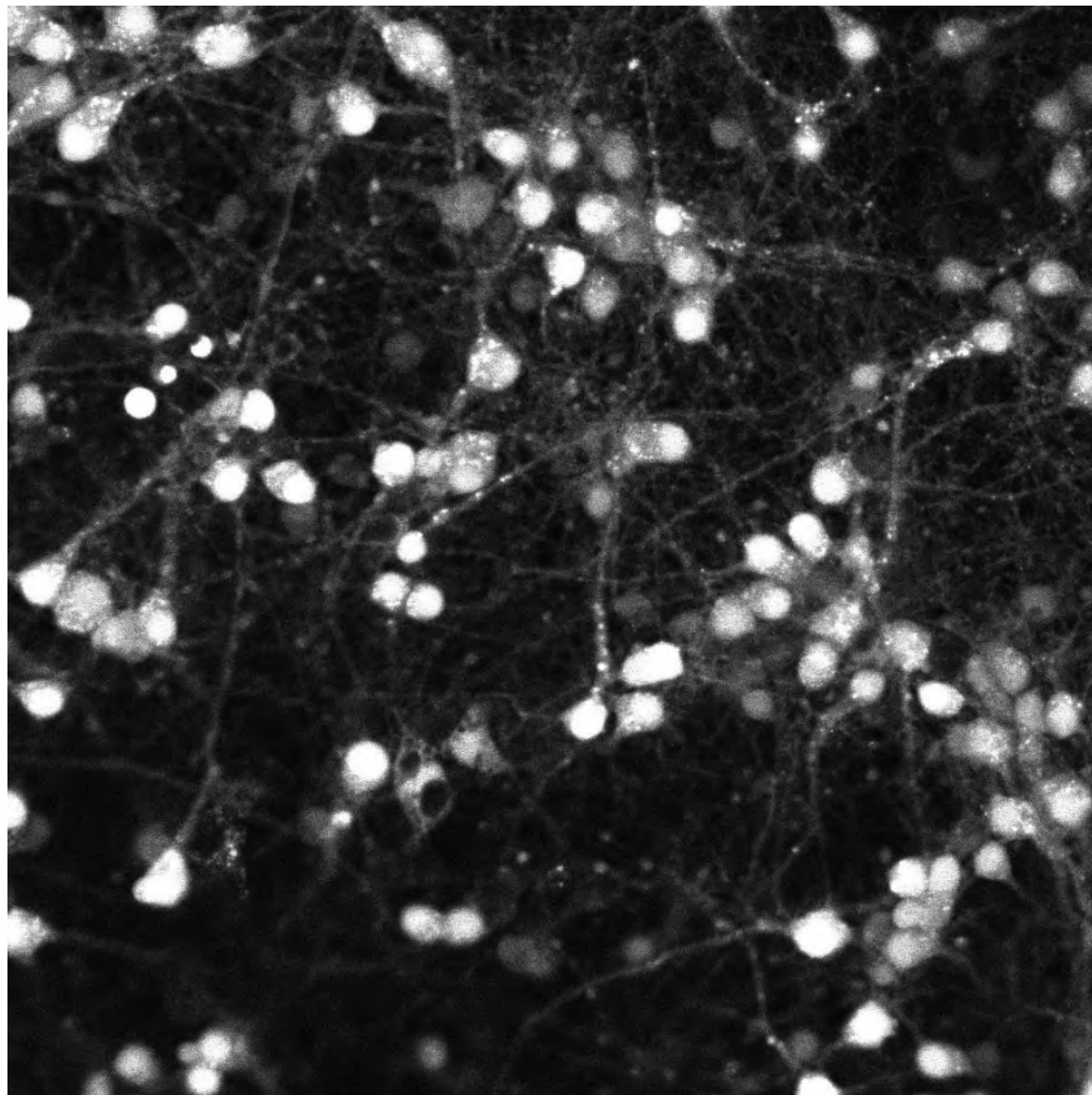


**Talking to neurons**

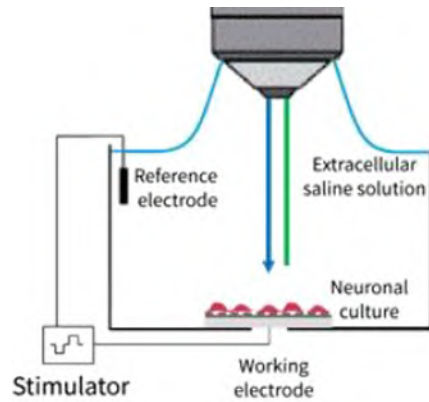


## Electrodes for neural excitation

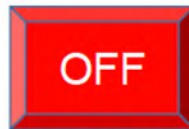
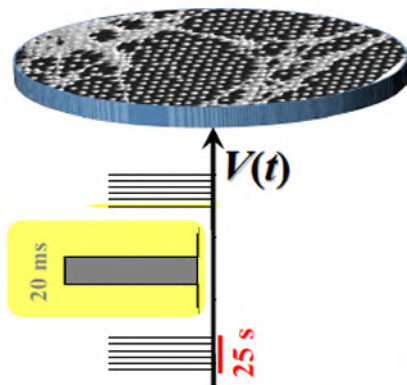
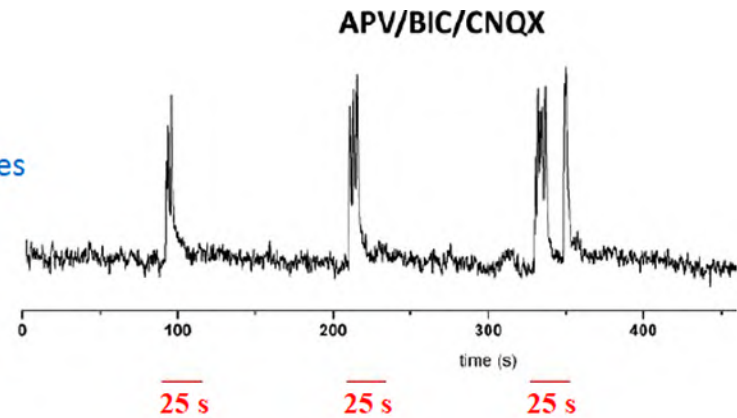




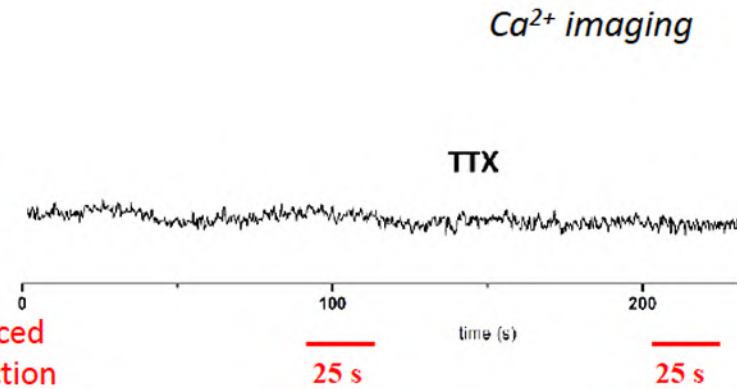
# Electrodes for neural excitation



Voltage driven  
activity in axon bundles



Pharmacologically induced  
complete blockage of action



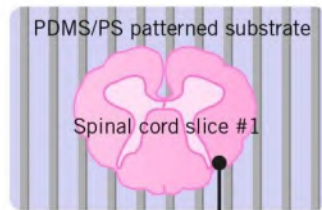
$Ca^{2+}$  imaging

TTX

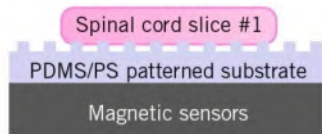
**Listening to neurons**



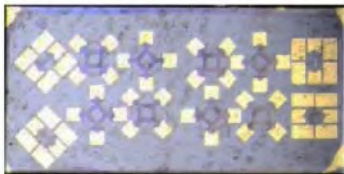
Top view



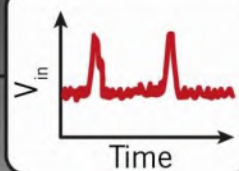
Side view



Anisotropic magnetoresistance sensors

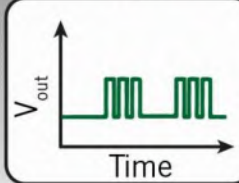


Input



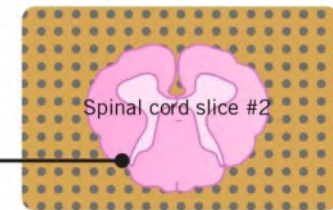
Trigger

Output

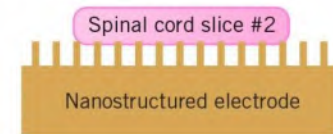


On-top-of-the-table electronics

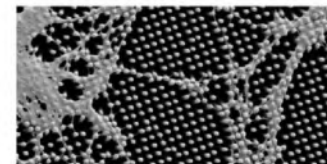
Top view



Side view



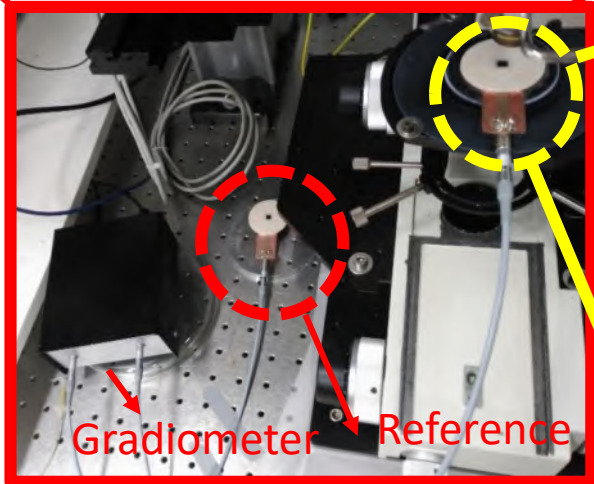
Nanostructured electrodes



# Proof of concept: detection of magnetic signals from spinal cord slices



Electronic set-up



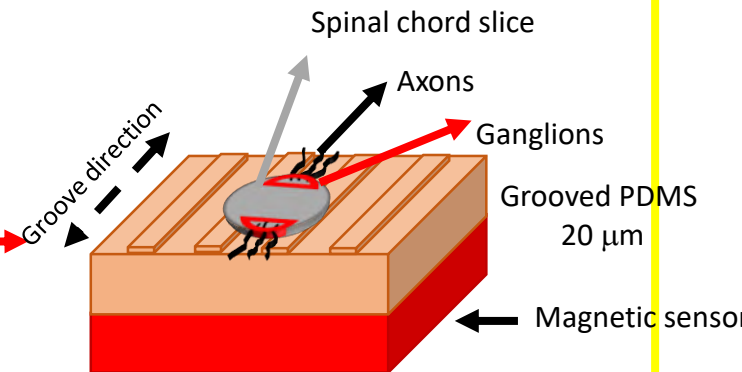
Magnetic (commercial TMR) and  
optic (Ca imaging) coupled devices  
for correlative measurements

Spinal cord slices from rats

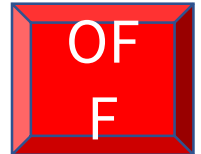
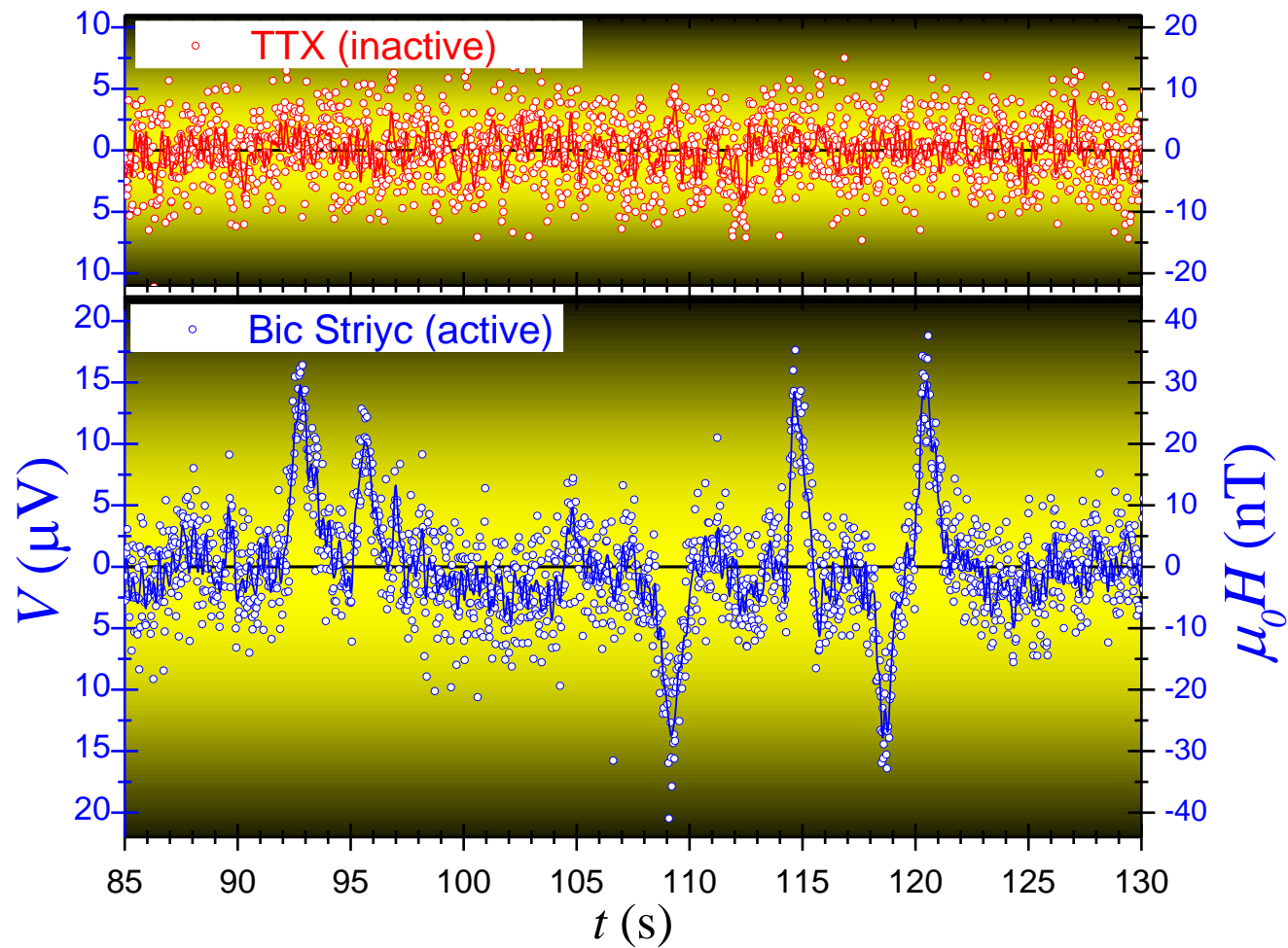
Ca<sup>2+</sup> set-up



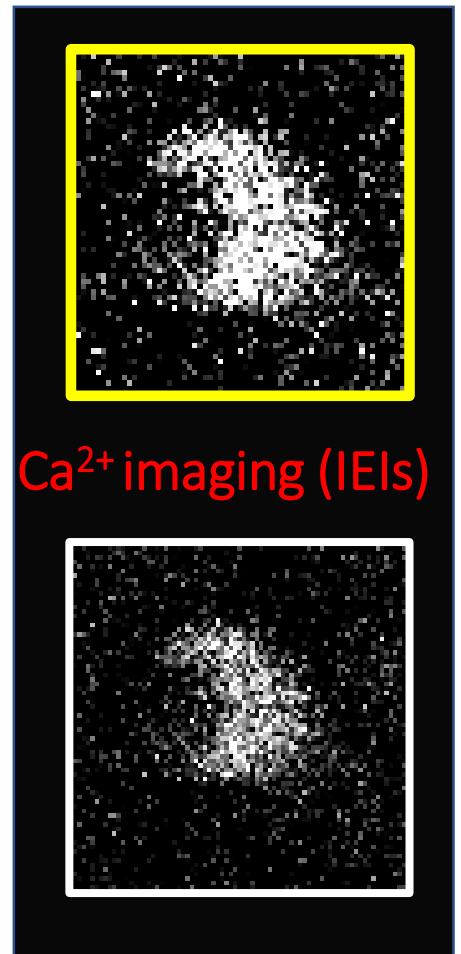
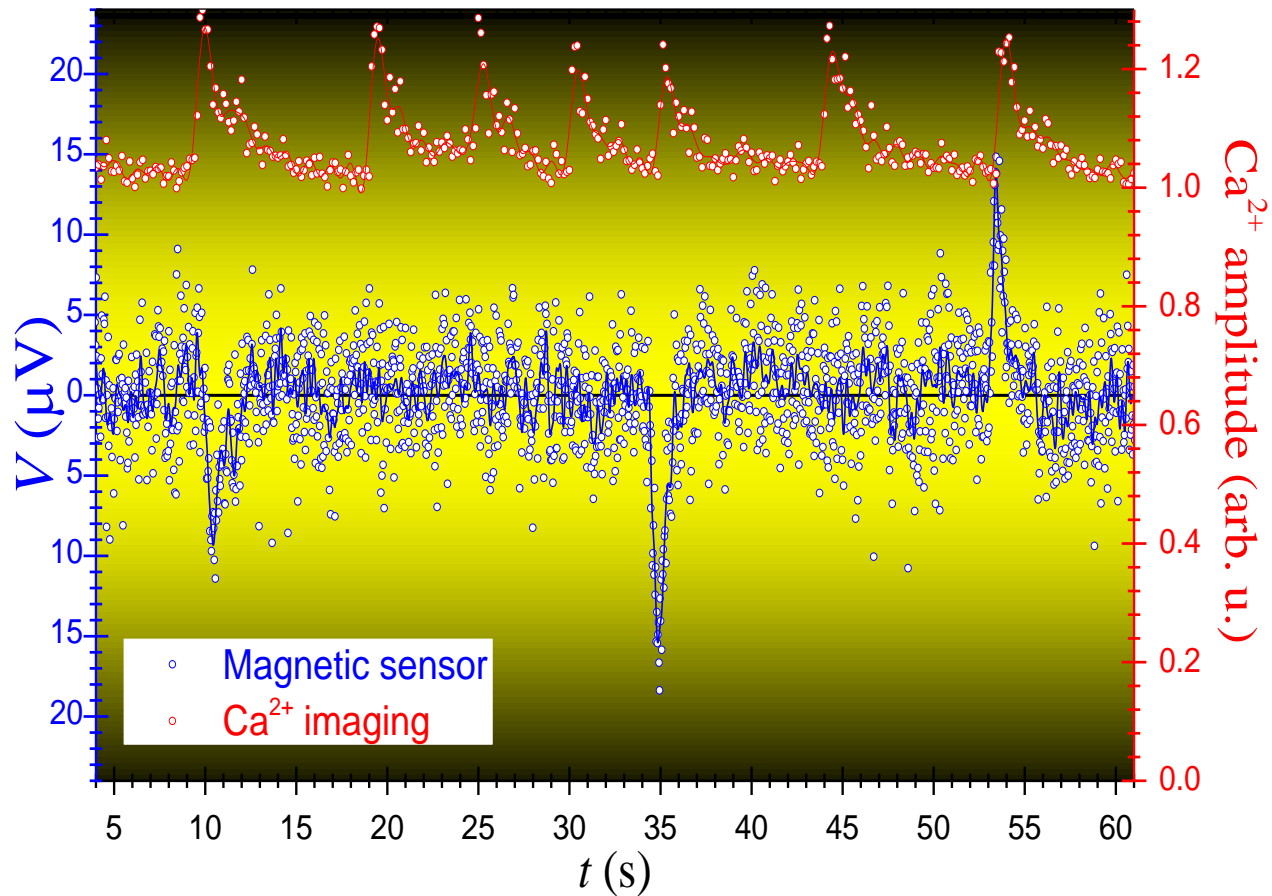
Grooved PDMS ~20  $\mu$ m



## Measurements without magnetic screening

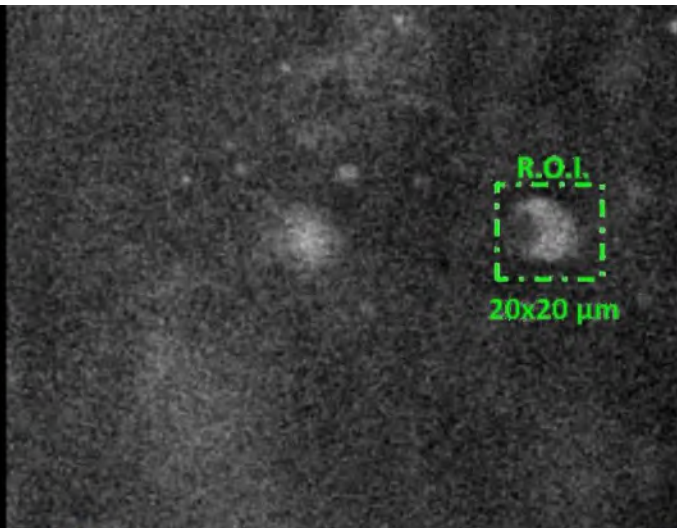


## Correlation between optical and magnetic signals

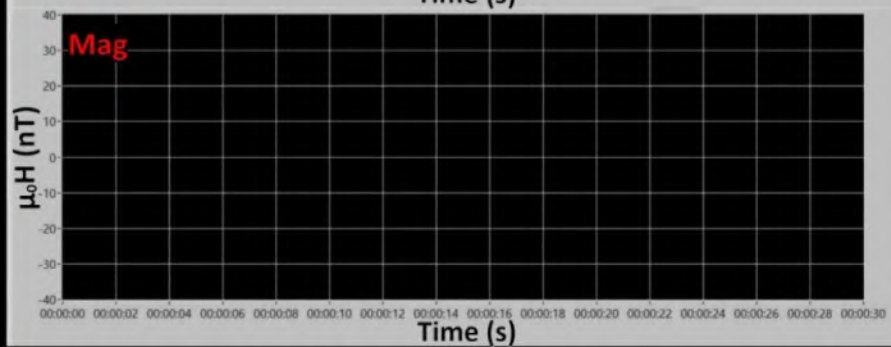
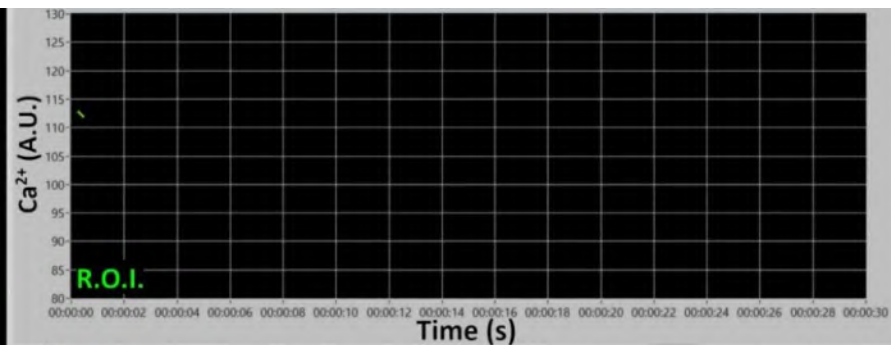




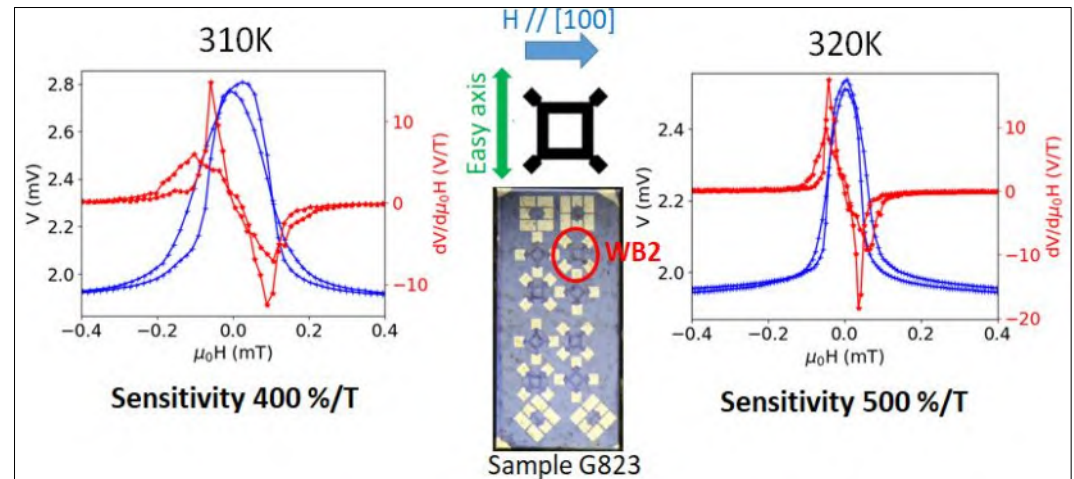
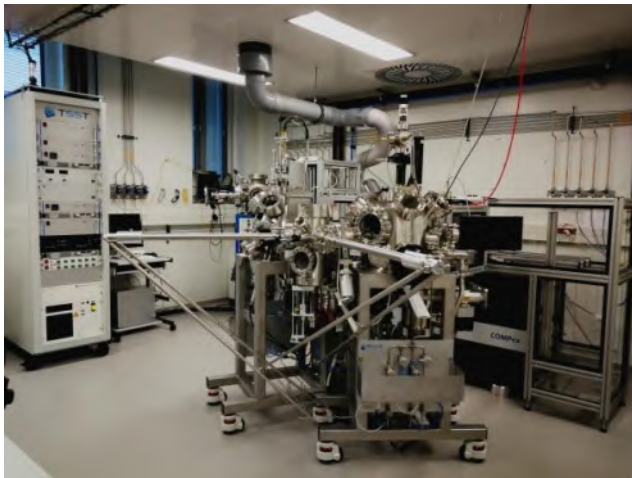
ON  
Bic-Stryc



00:00:00,00



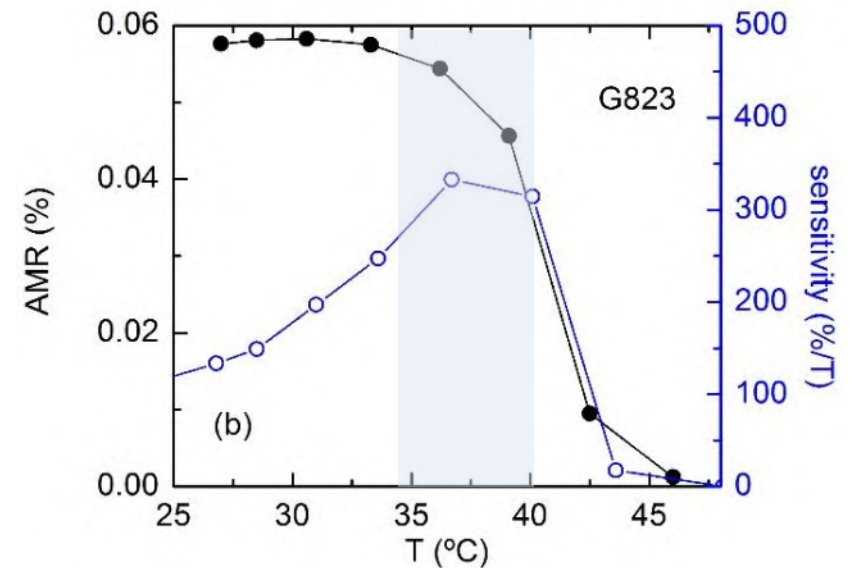
# New generation of spintronics sensors



Magnetic sensor based on:

- AMR
- TMR
- Gradiometer configuration

Large sensitivity in the biological interesting temperature region



## Take home message

People from...

... sensing

.... spintronics

We have an opportunity!

## Take home message

People from...

... sensing

.... spintronics

**We have an opportunity!**

This is probably not the most fancy are for people coming from nanomagnetism and spintronics...

... but we can really make a a change!