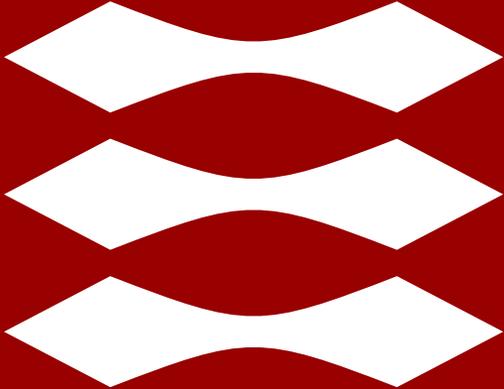
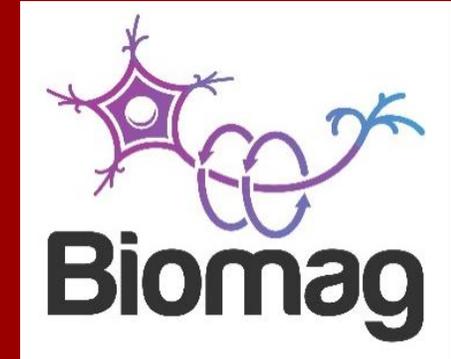


DTU



# From Colour Centres in Diamond to Magnetic Microscopy

Image by Casper Breum and Haitham El-Ella



# CBQS



# Non-invasive approach for measuring current!

H. C. Ørsted, 1820

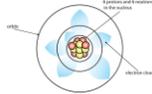
# Quantum Sensing – Platforms

## Light



- refractive index/phase shifts, absorption, scattering, space-time (gravitational waves)

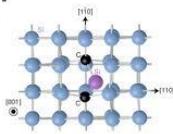
## Atomic systems



- Electric field, magnetic field, gravity

## Atomic-like systems in solid-state

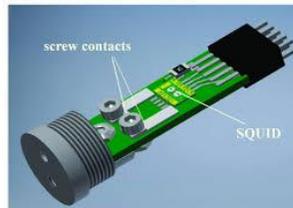
(defects, impurities, QDs)



- Electric field, magnetic field, temperature, pressure

## Engineered systems

(SQUIDS, EMR, mechanics)



- Electric field, magnetic field, temperature, pressure, acceleration

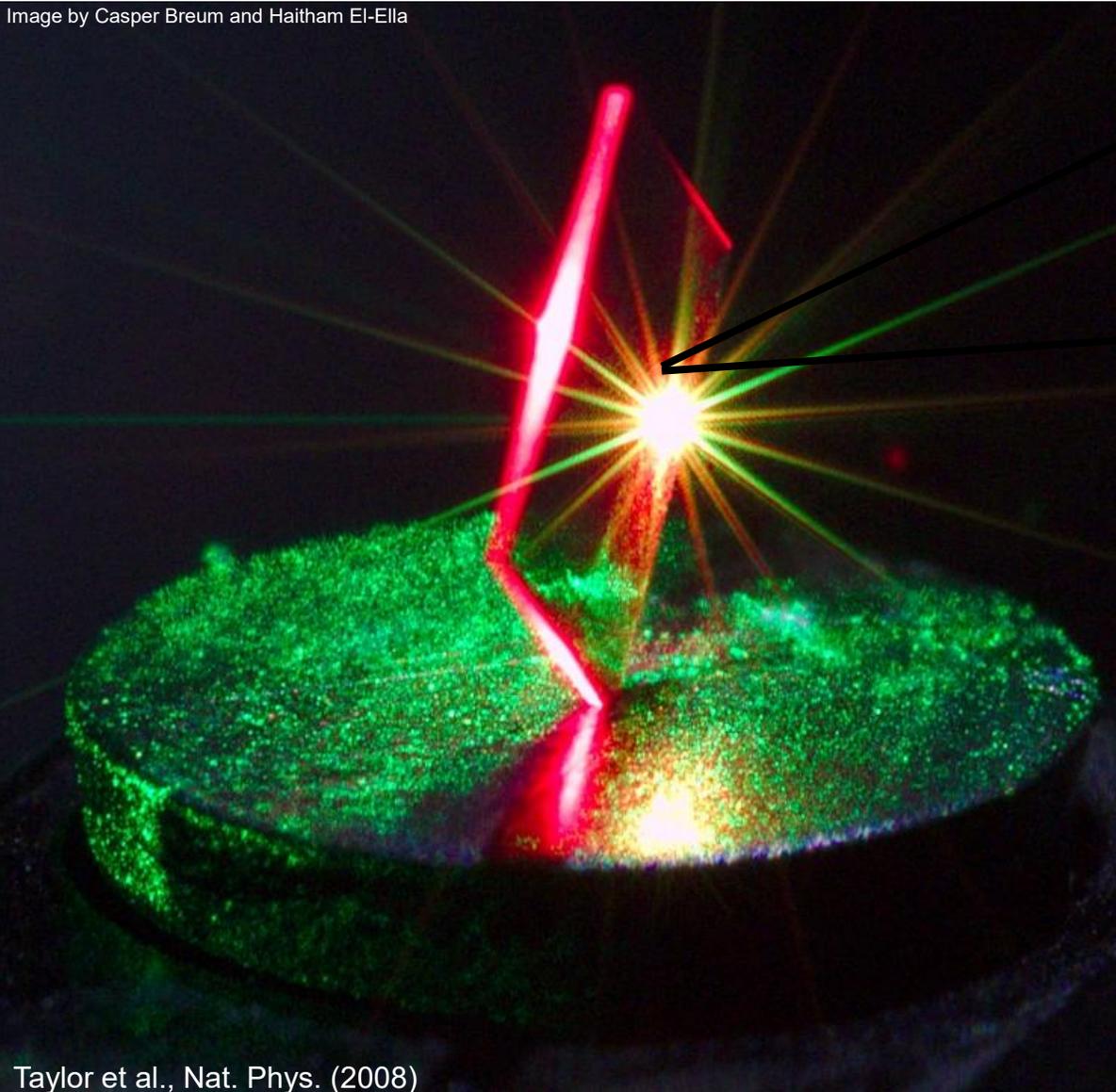
# Diamond colour centres

	natural diamonds	treated natural diamonds	synthetic and treated diamonds
Ia			
Ib			
IIa			
IIb			

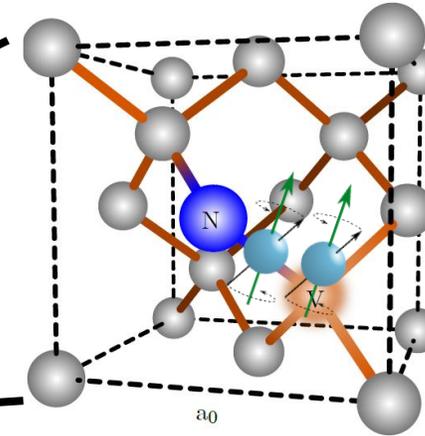
Coloured diamond: >500 defects known in diamond

# Diamond NV<sup>-</sup> centres

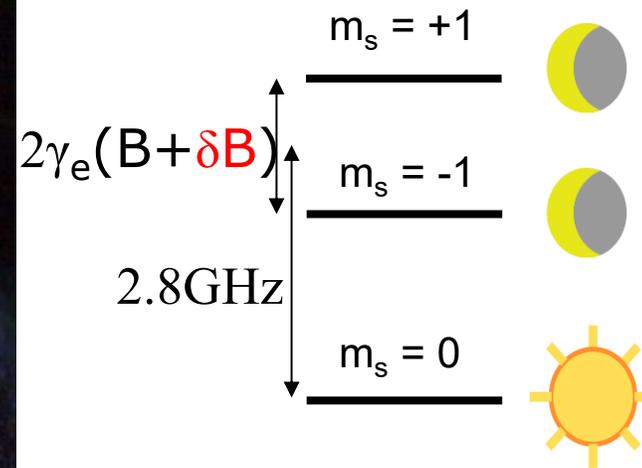
Image by Casper Breum and Haitham El-Ella



Taylor et al., Nat. Phys. (2008)



## The key features:

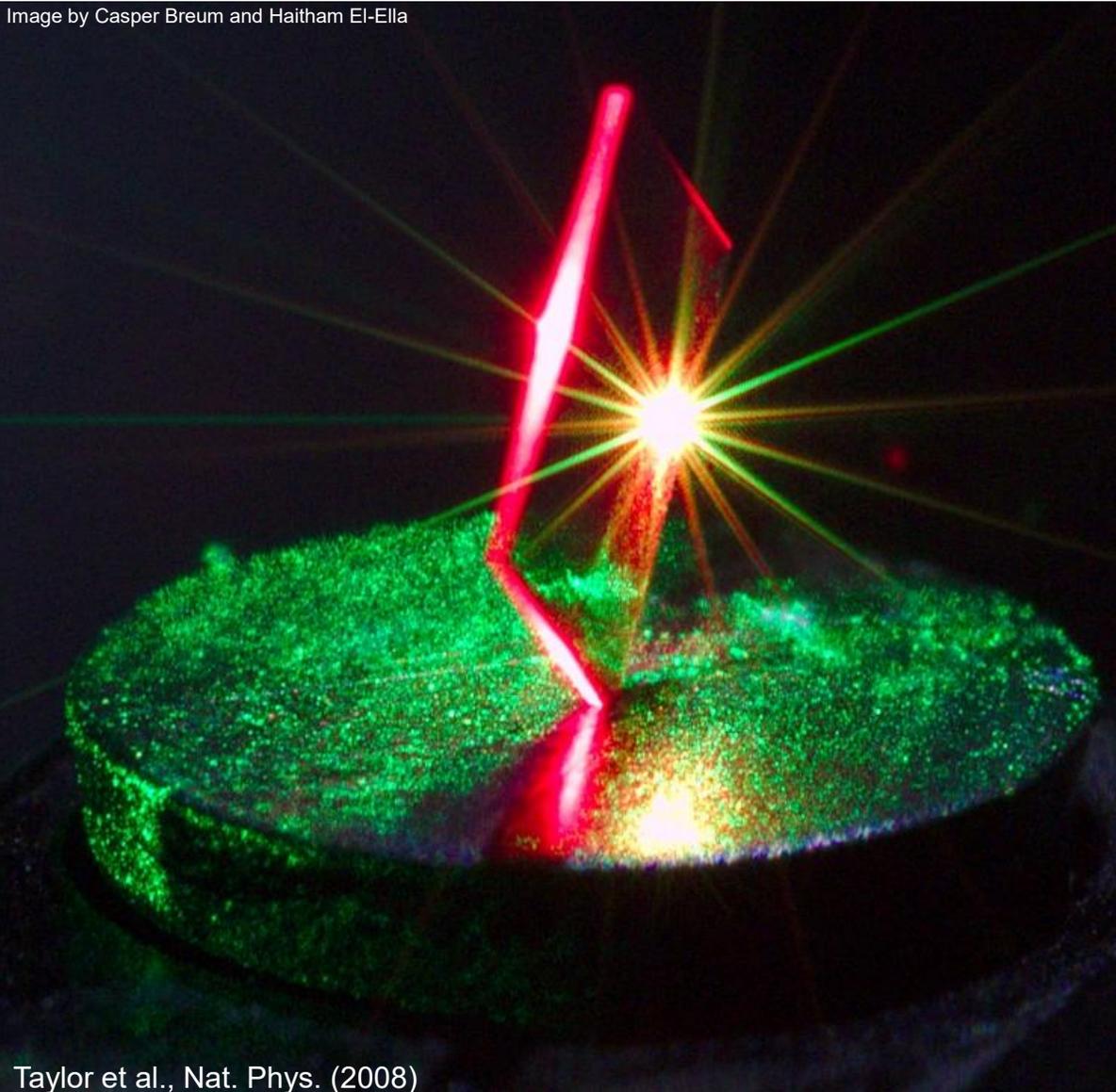


- Optical spin readout
- Spin polarization with  $\sim$ ms lifetime ( $T_1$ )
- $\gg 10\mu$ s long spin coherence
- room temperature, solution, pressure, etc.

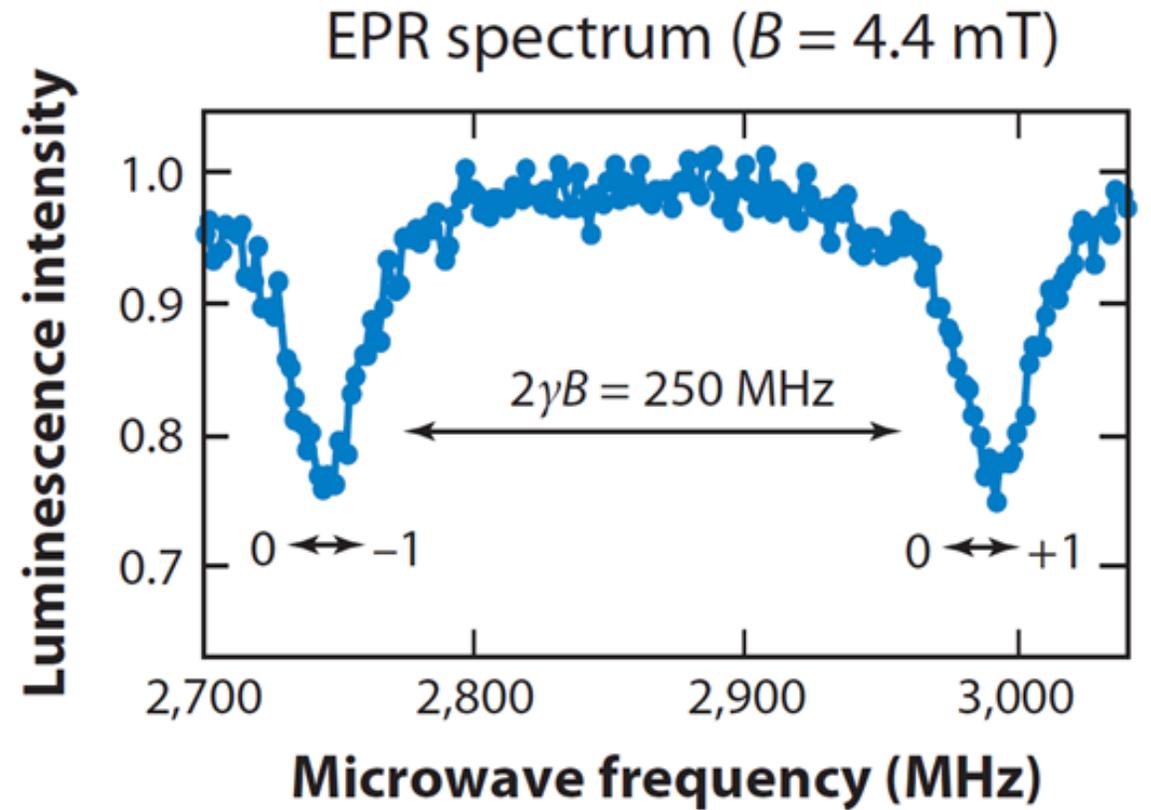
*Magnetometry*  $\equiv$  Spectroscopy of magnetically sensitive energy levels

# Diamond NV<sup>-</sup> centres

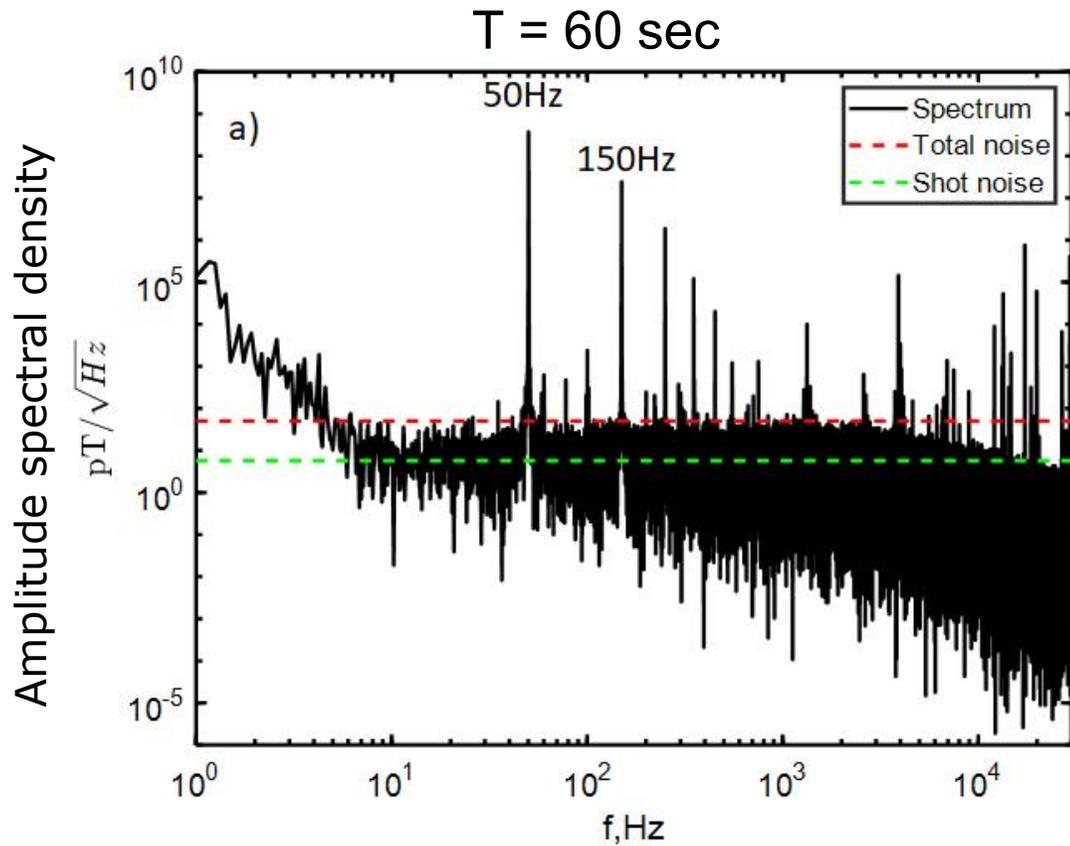
Image by Casper Breum and Haitham El-Ella



Taylor et al., Nat. Phys. (2008)



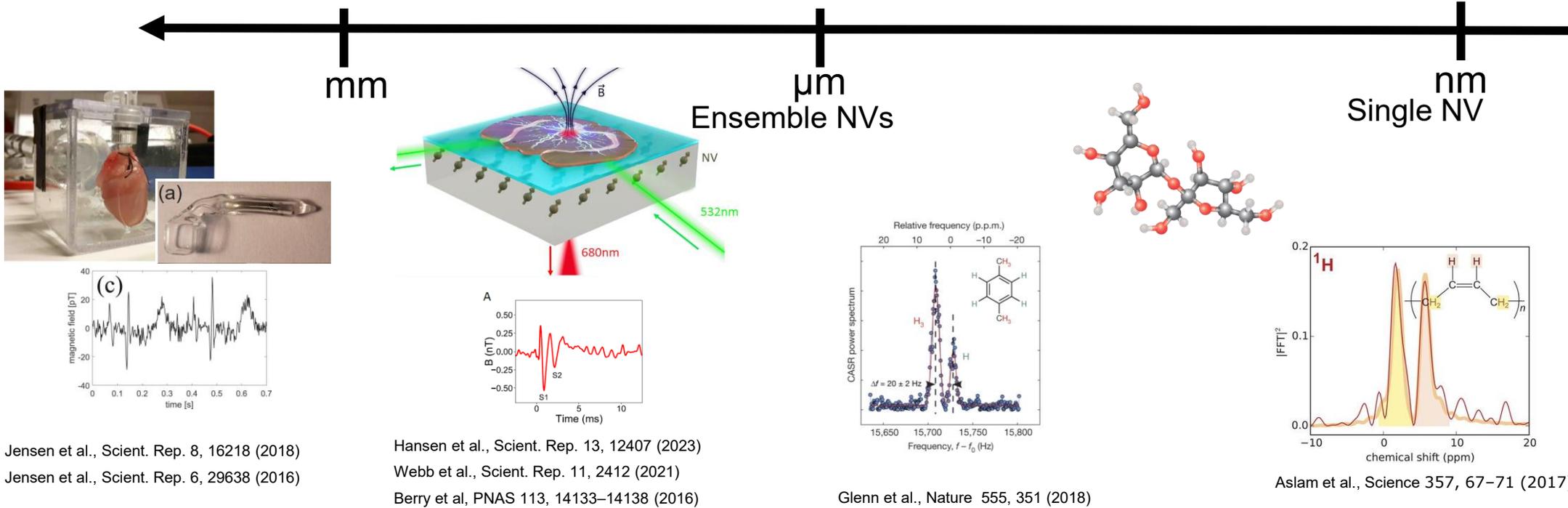
# Sensitivity and stability



Sensitivity 30 - 50  $\text{pT Hz}^{-1/2}$

Stable operation for many hours

# Sensing at the micro- to nano-scale



## Application areas:

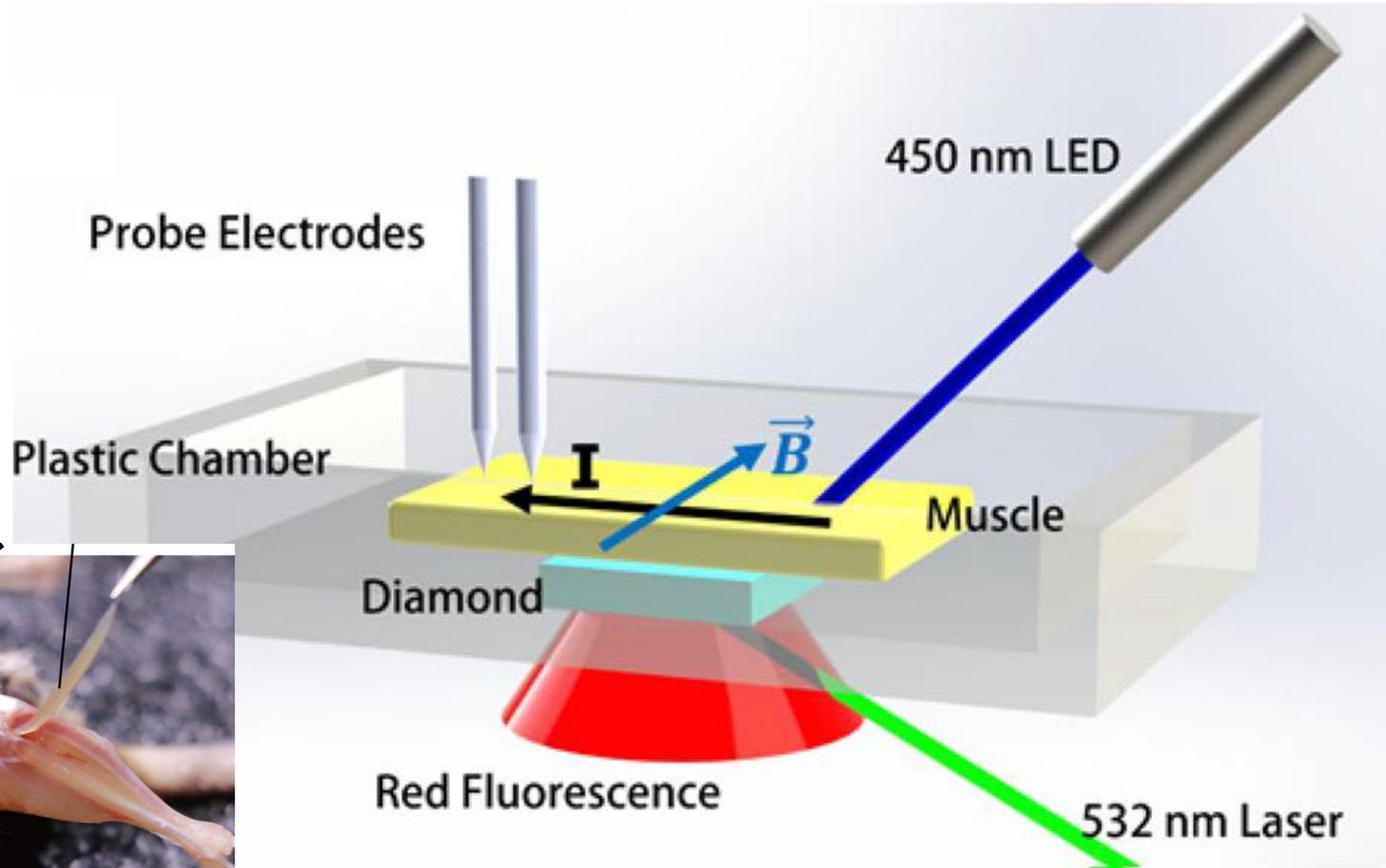
Non-invasive sensing in biology - recording induced biomagnetic fields

Molecular scale sensing of spin-chemistry, NMR with chemical resolution, metabolism

# The Diamond Experiment

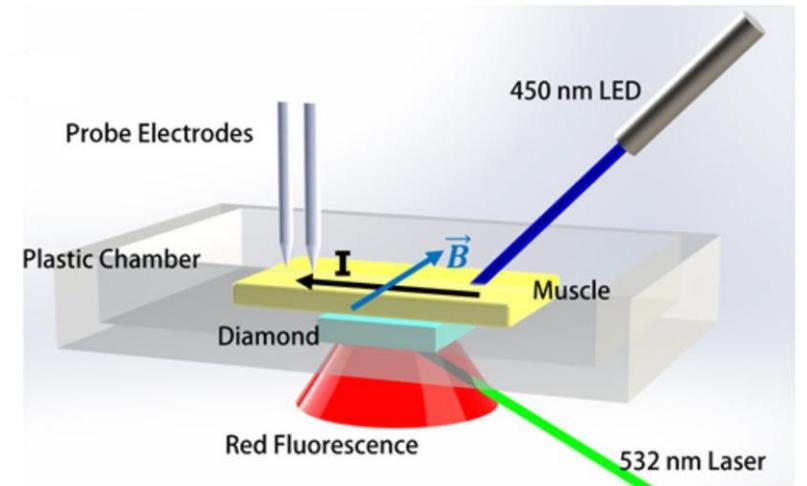
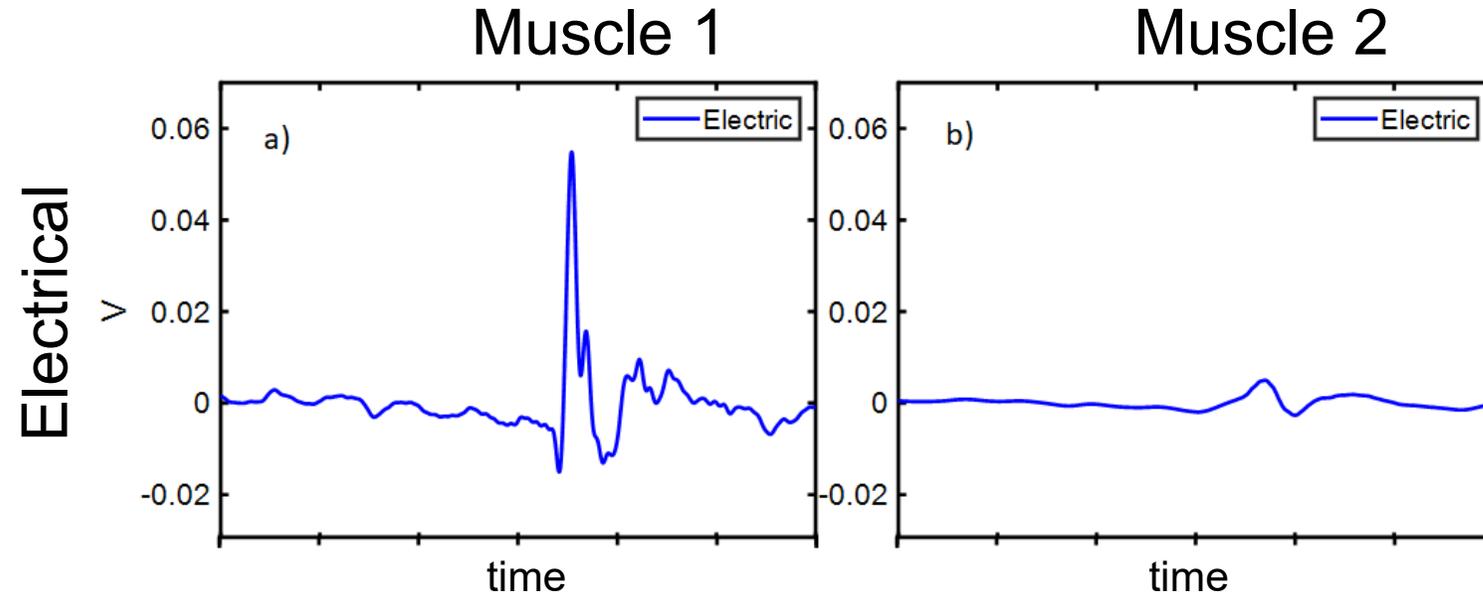
Solution bath:

- Artificial cerebrospinal fluid (ACSF)
- CO<sub>2</sub> and O<sub>2</sub> saturated
- temperature at 34°C



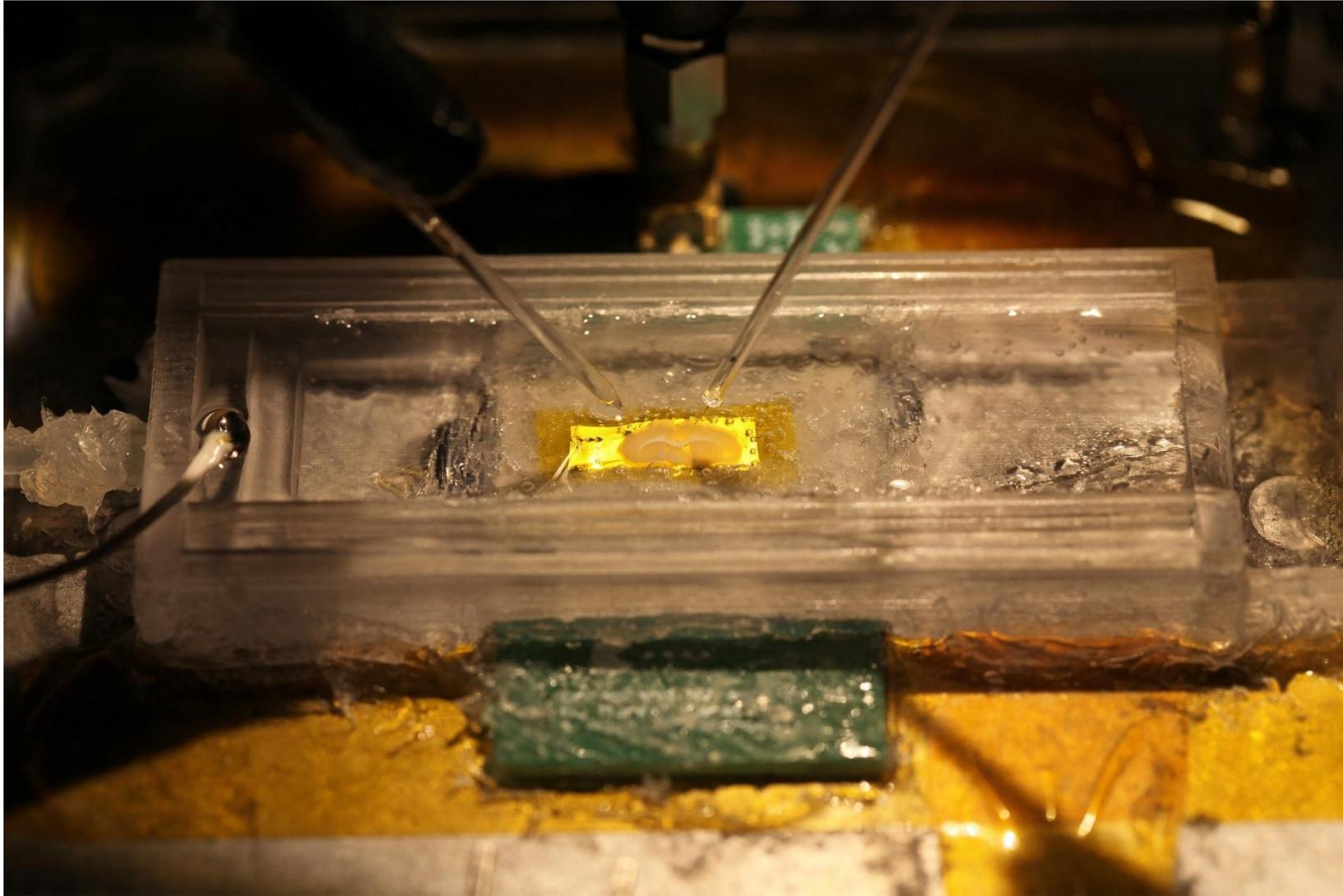
Webb et al., Sci. Rep. 11, 2412 (2021)

# Electrical vs. magnetic signals



Webb et al., Sci. Rep. 11, 2412 (2021); pioneering work by Barry et al., PNAS 113, 14133-14138 (2016)

# The experiment with brain tissue



Webb et al., Sci. Rep. 11, 2412 (2021)

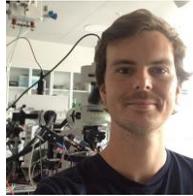
# Corpus Callosum - experiment



Webb

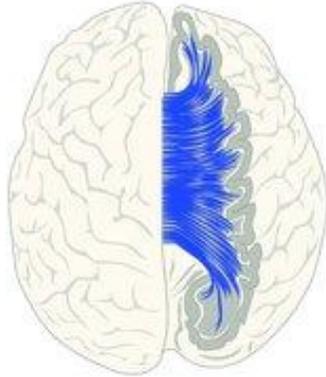


Troise

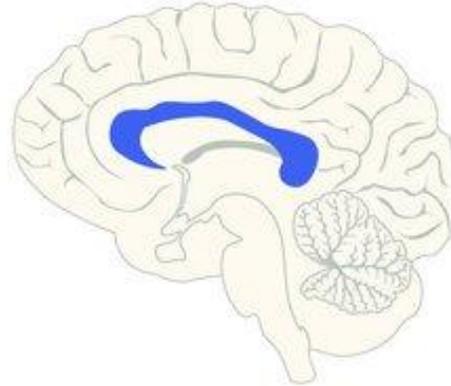


Hansen

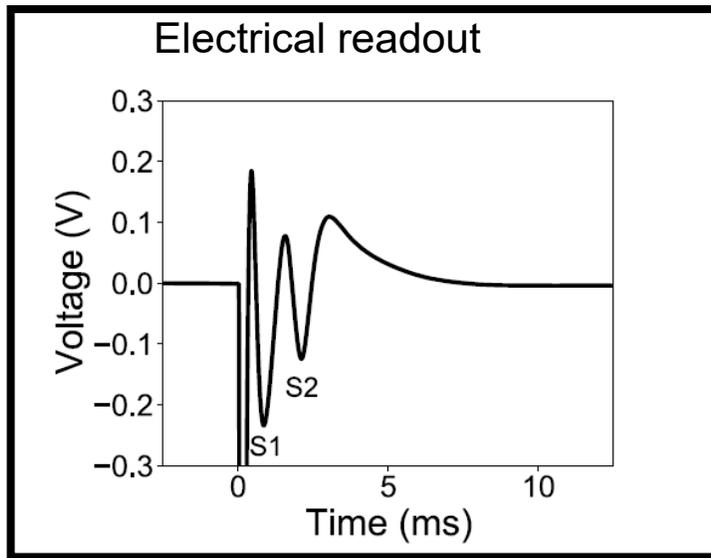
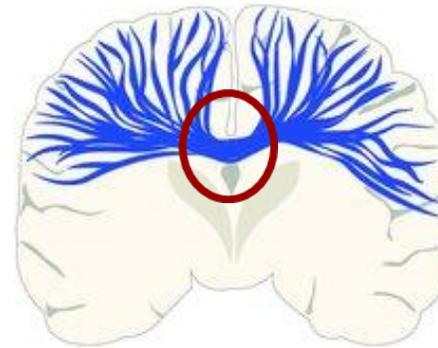
A Dorsal



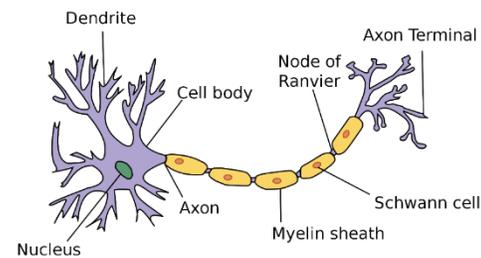
B Sagittal



C Coronal



~60% with Myelin



# Magnetic widefield imaging – What is the challenge?



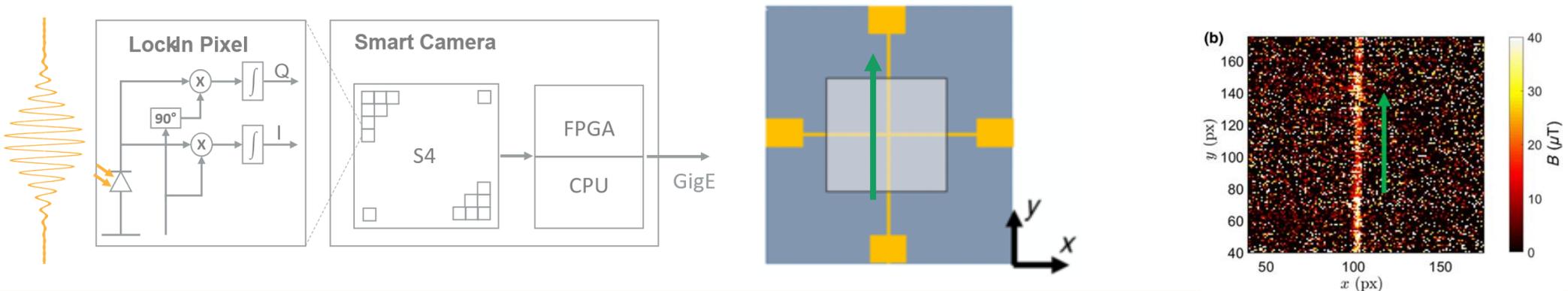
- CCD/CMOS camera technical limitations
- Tradeoff between speed and sensitivity

Adam M. Wojciechowski et al., Rev. Sci. Instrum. 89, 031501 (2018)

## One exception: Lock-in camera

- high-speed ( $>10\text{kHz}$ )
- Low-sensitivity,  $\sim\mu\text{T}$

Webb et al., Phys. Rev. Applied 17, 064051 (2022)



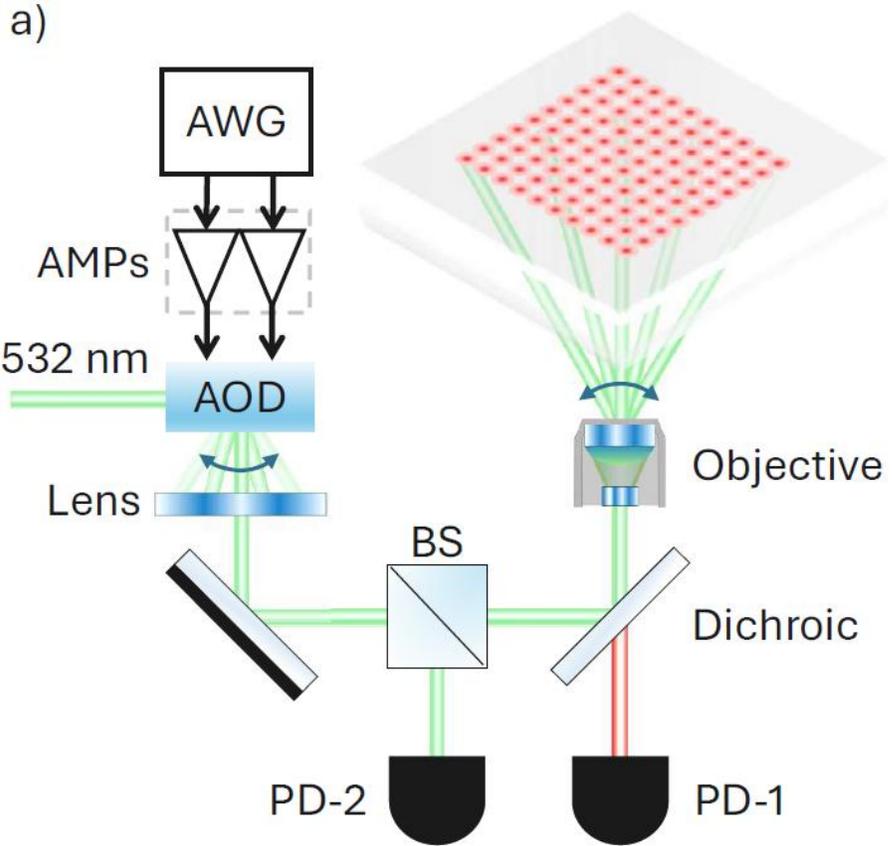
# Magnetic widefield imaging – Our approach



L. Troise



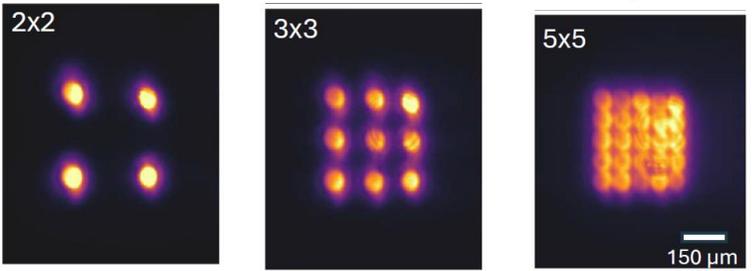
M. Holten



## New imaging approach

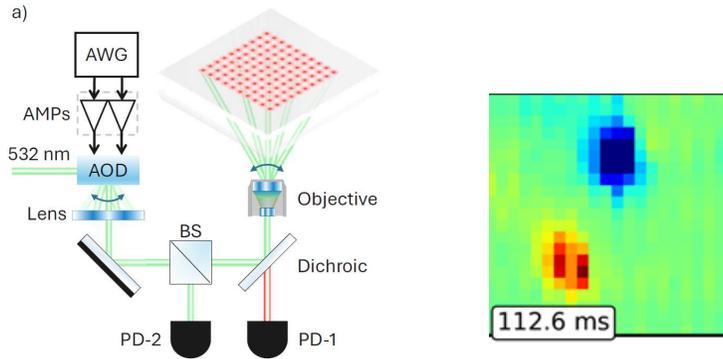
- high-speed, frame-rate  $>10\text{kHz}$
- Diffraction limited resolution  $1\text{-}20\ \mu\text{m}$
- Sensitivity  $<1\text{nT Hz}^{-1/2}$

L. Troise et al., patented and in submission

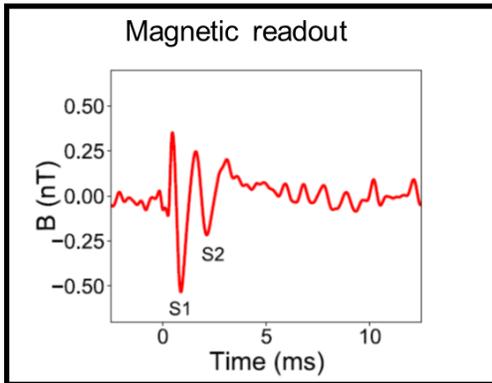


# What is next?

## Foundation



- Patented technology



- Proof of concept

**Vision:** Developing the worlds *fastest* and *most sensitive* magnetic microscope with the *highest resolution* (microscopic).

# Thank you!



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# Questions?

