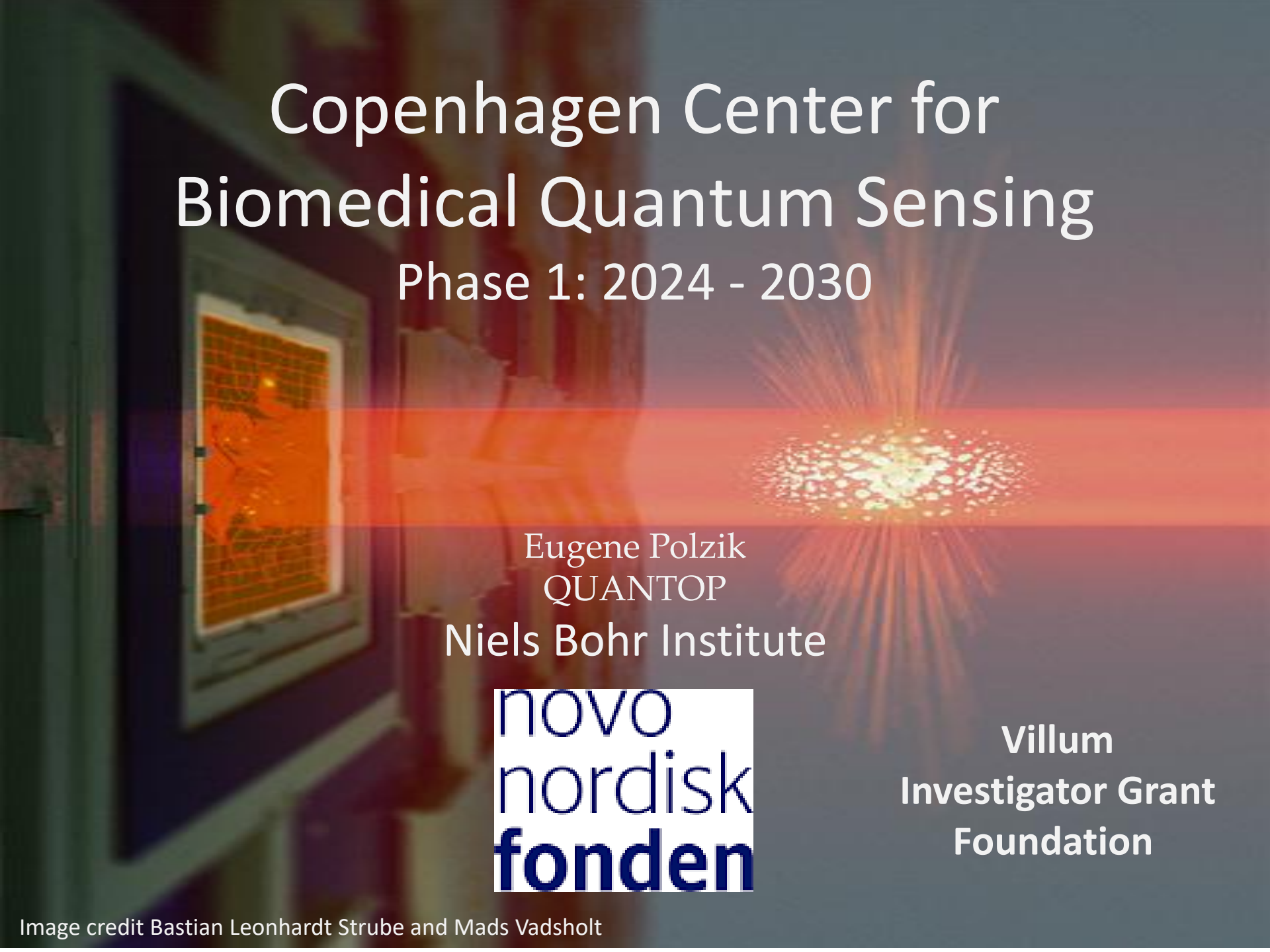


Copenhagen Center for Biomedical Quantum Sensing

Phase 1: 2024 - 2030

Eugene Polzik
QUANTOP
Niels Bohr Institute

novo nordisk fonden

Villum Investigator Grant Foundation

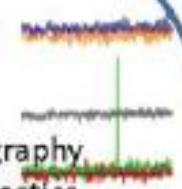
Image credit Bastian Leonhardt Strube and Mads Vadsholt

Center composition and major thrusts

NBI KU

Center leader, PI – Eugene Polzik

Entanglement assisted sensing for bio-medical applications



Atomic bio-magnetometry

Quantum magnetic induction tomography

Entangled light for life science diagnostics

Optimal quantum sensing

Light quantum conversion and memory for sensing

Atomic sensors for enhanced MRI imaging

UT AUSTIN

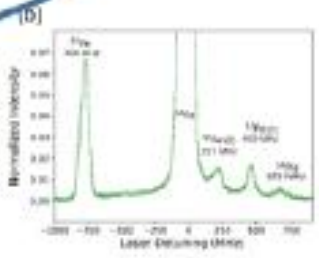
PI – Mark Raizen

Atomic Medical Diagnostics and Cures

Detection of metabolic changes by isotope ratios

Prevention of malnutrition and toxicity by isotopic tracers

Quantum limited acoustic detection



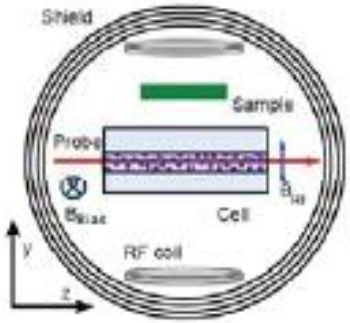
DTU

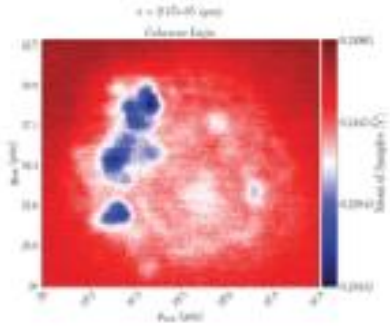
PI – Ulrik Andersen

Quantum-enhanced sensing and imaging

Diamond-based quantum sensing and imaging of cells and molecules

Squeezed-light enhanced light control, spectroscopy and microscopy





High level scientific goals for the Center for Biomedical Quantum Sensing include

- approaching and surpassing standard quantum limits in magnetometry, spectroscopy, microscopy and isotope separation
- discovering novel efficient methods for generation of entangled states of radiation and matter allowing for surpassing those limits
- using quantum enabled technology to advance medical diagnostics and healthcare

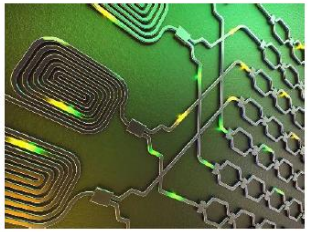
Our vision is to bring advances in quantum technologies into medical diagnostics and healthcare.

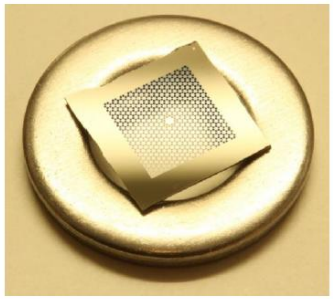
We will collaborate with:

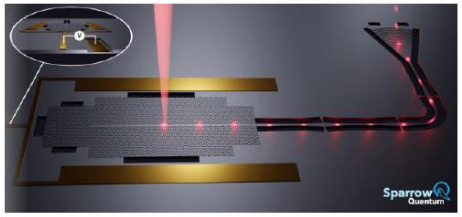
- NNF Quantum Computing program
- Quantum Innovation Hub in Copenhagen
- Quantum Foundry

Quantum Sensing

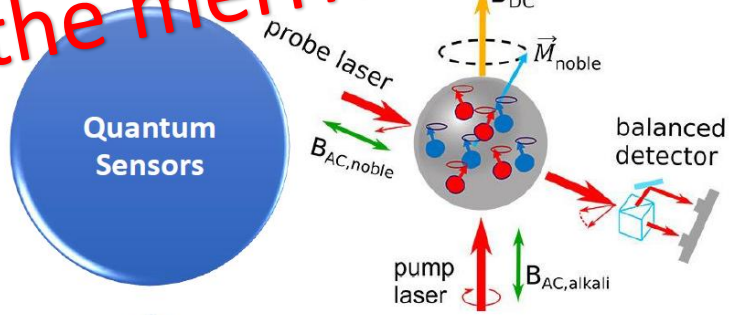
Quantum Technology







The more qubits, the merrier!



~1 qubit per pulse

10-100 qubits

Entangled state of 10^9 spins

Only very special types of such states survive

High symmetry helps

- single mode squeezed states

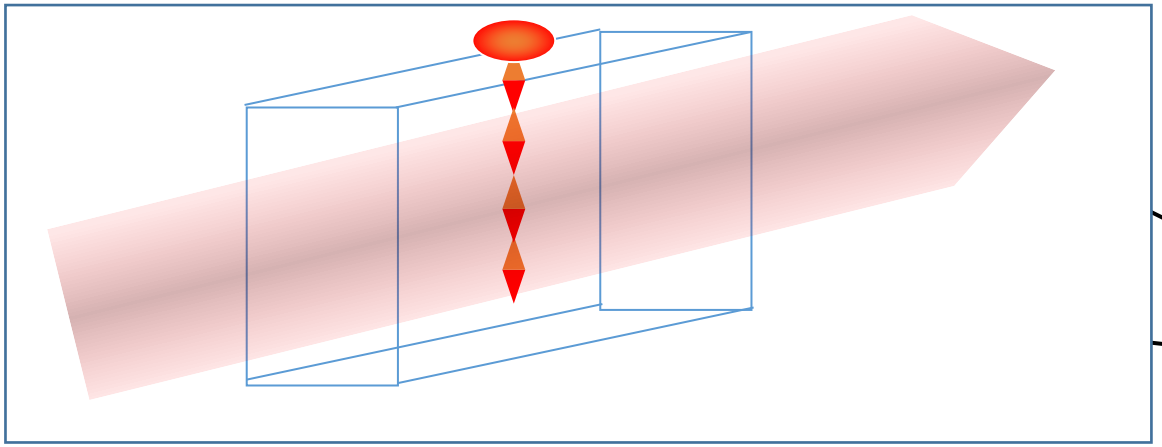
- two mode squeezed states = EPR entangled

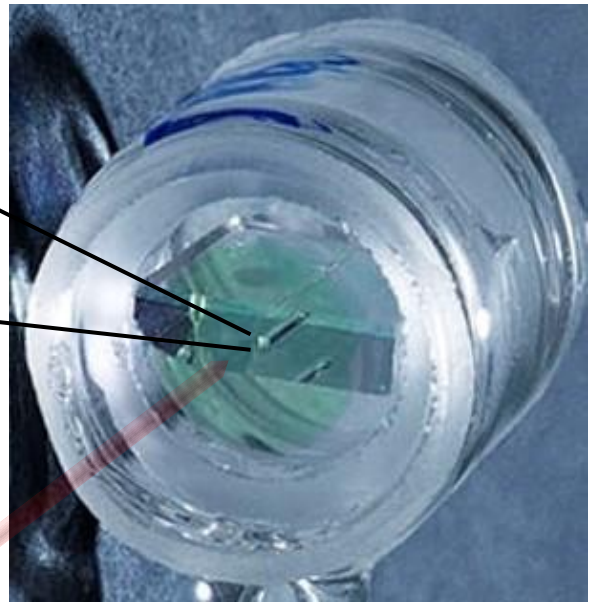
Julsgaard et al ***Nature*** 2001; Sherson et al ***Nature*** 2006; Thomas et al **Nature Physics** 2021

- symmetric collective single excitations (Fock states)

Dideriksen et al **Nature Comm** 2021

Sensor Type I: spin of 10^9 - 10^{12} Room T Atoms



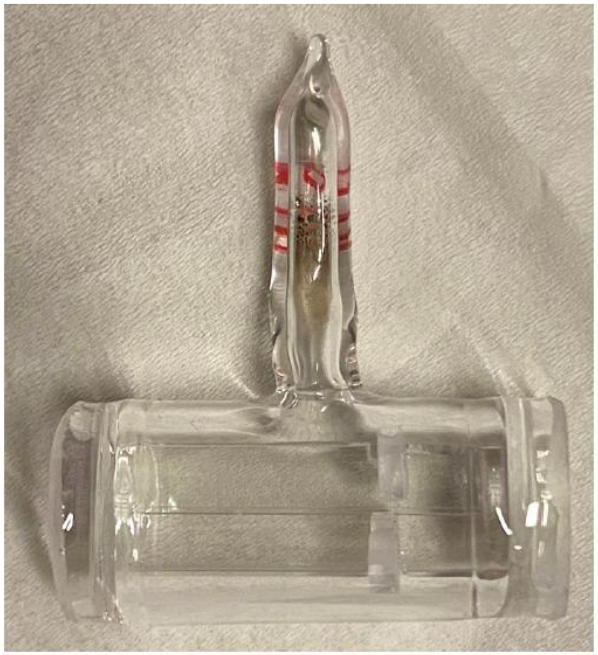


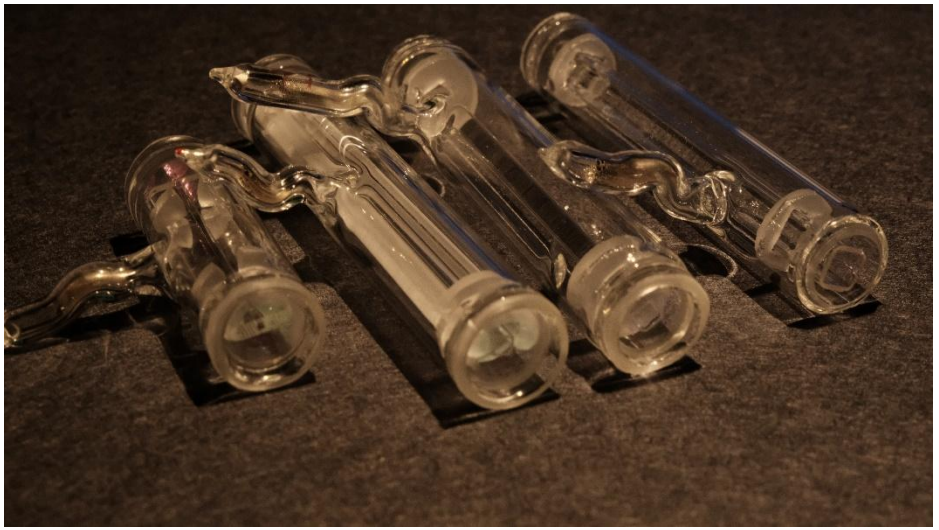
To generate a long-lived collective spin wave:

- Light-spin interaction without ”which atom” information
  - Spin protecting coating of cell walls prevents collisional decoherence

life time of
a spin state ~0.01 – 1 sec at room temperature

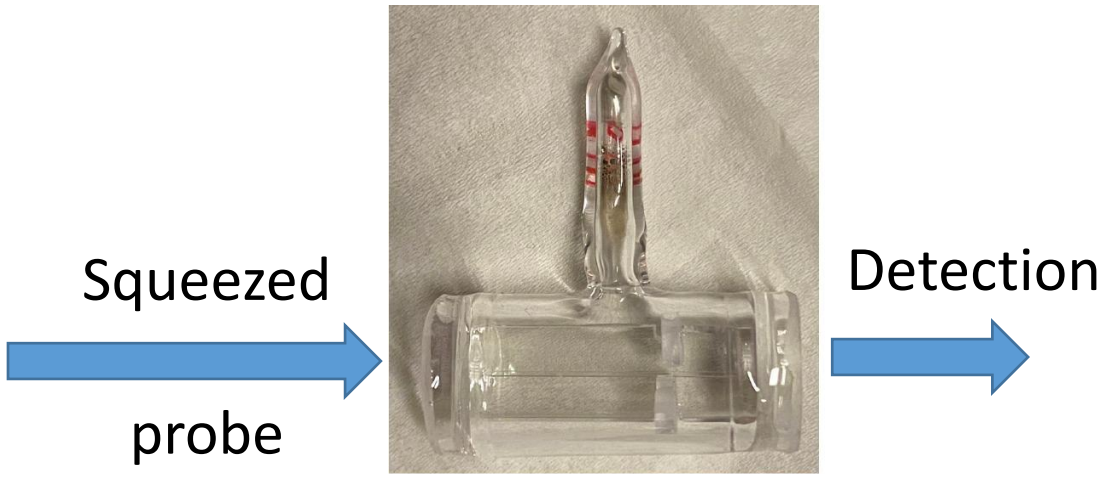
Sensor: vapor of room temperature atoms in spin protected environment





Design and fabrication credit: Mikhail Balabas

Quantum noise limits of sensing



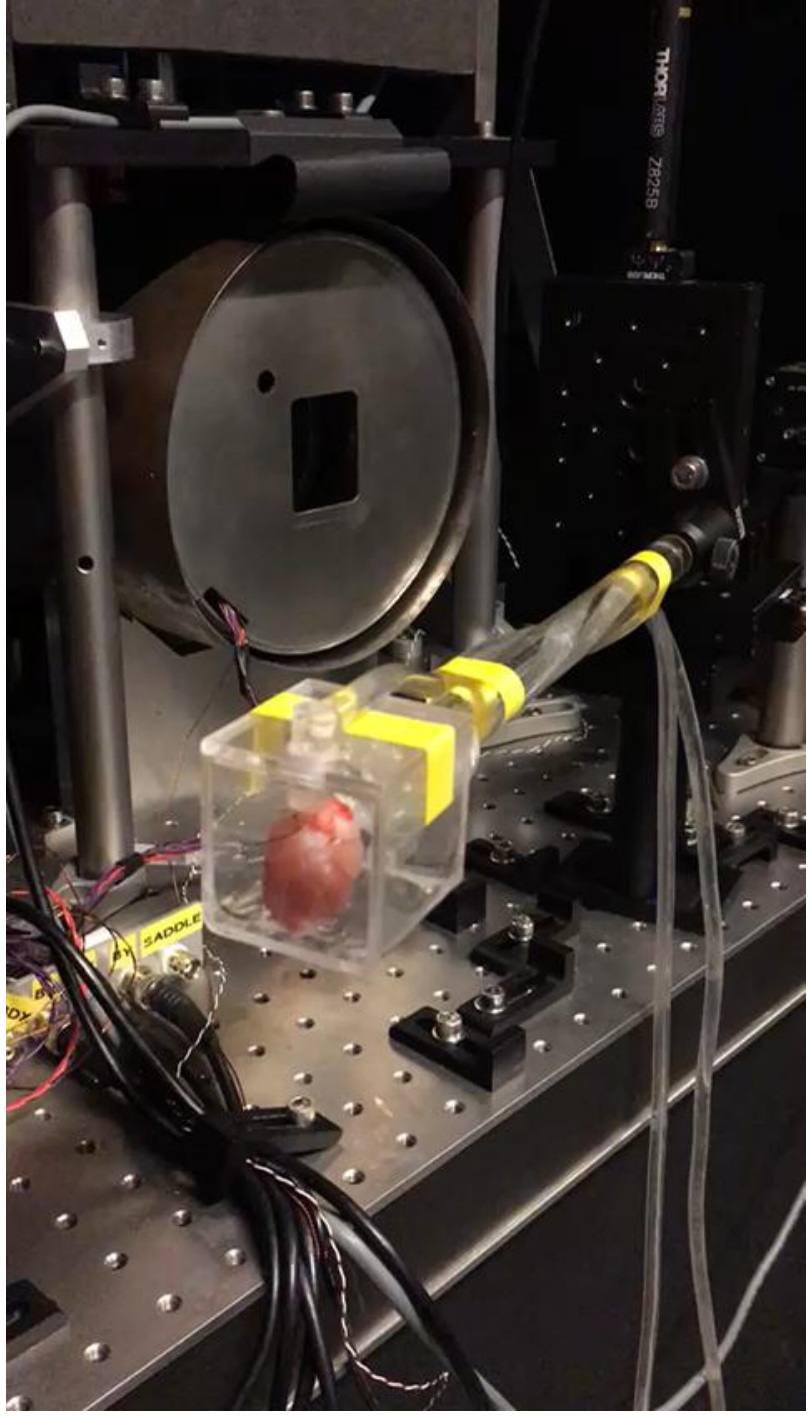
Shot noise of light

Measurement rate

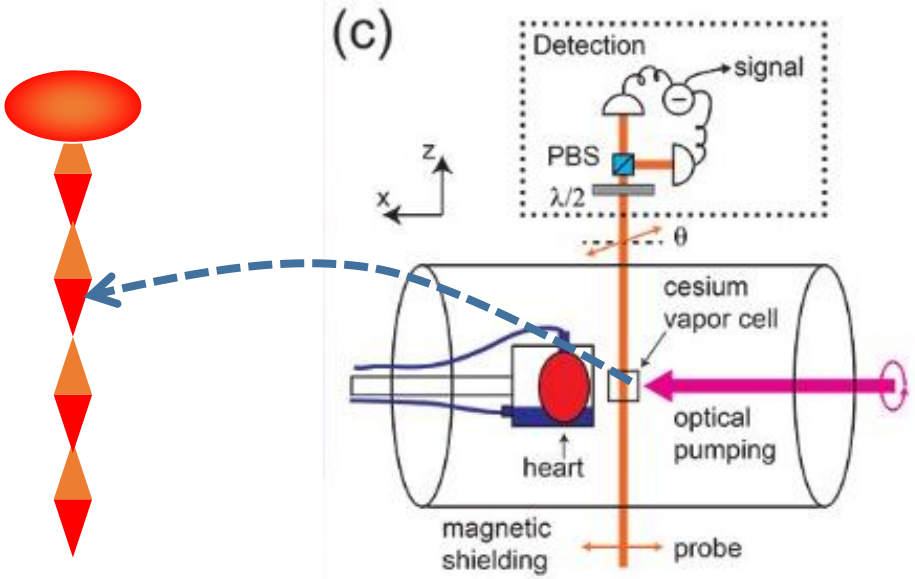
Back action of light

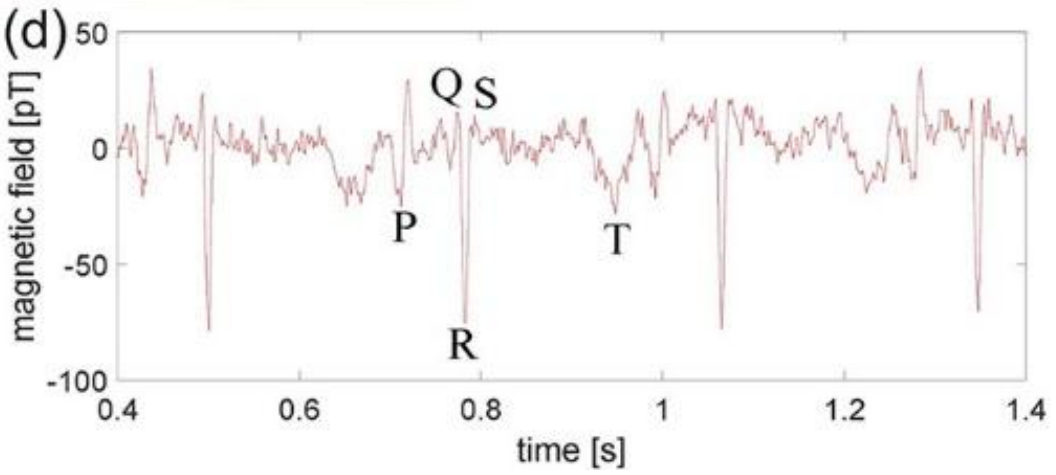
$$P_{L1,out} = -P_{L1,in} + signal + \Gamma \chi X_{L1,in}$$

Squeezed Light probe



Atomic Spin magnetometry for **Noninvasive cardiac diagnostics**

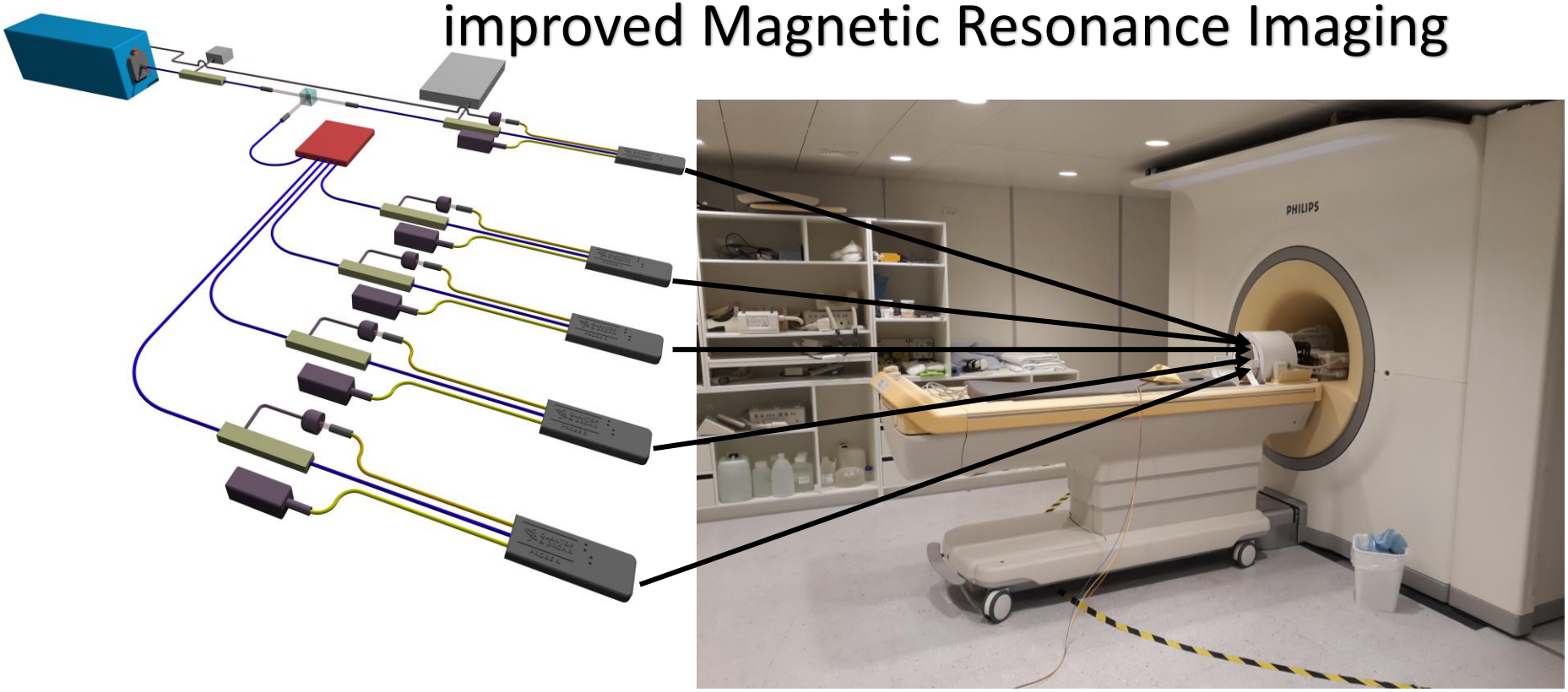




NBI collaboration with Rigshospital, Copenhagen

Sensor type II:

improved Magnetic Resonance Imaging



7 Tesla magnetic field measured with 10^{-7} (1 part in 10 million) accuracy

Hans Stærkind; Collaboration NBI – Hvidøvre Hospital, Copenhagen

MAGNOLIA
QUANTUM SENSING

We develop and deliver the world's first **high-field optical quantum magnetometer for MRI**

Unlocking a new era of accuracy, efficiency, and global accessibility in advanced medical imaging

Founding Team

Hans Stærkind, CEO
PhD, Quantum Optics/MRI, NBI/DRCMR
Business Development, Technology, Applications
EXAAQ technology development, MRI applications exploration, and business planning since 2017

Kristin Engel
PhD Fellow, MRI, DTU/DRCMR
Applications, User Experience, Marketing
Ultra-high field MRI engineering research since 2023, first research user of the EXAAQ prototype

Asger Pedersen
MSc, Physics, Tokyo Tech
Technology, Production, R&D, Supply Chain
R&D project management in optics and semiconductor industry since 2019

Susanne Stærkind
MSc, Political Science, UCPH
Organization, Administration, Communication
Collective agreements, settlements, legal interpretations, and work environment in hospital administration since 2018

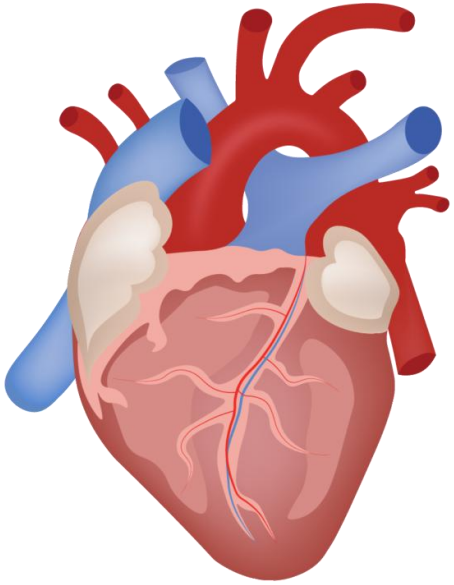
Jörg Müller
Assoc. Professor, Quantum Optics, NBI
Technology, R&D
EXAAQ technology development since 2017
Academic research in optics, quantum, and atomic physics since 1989

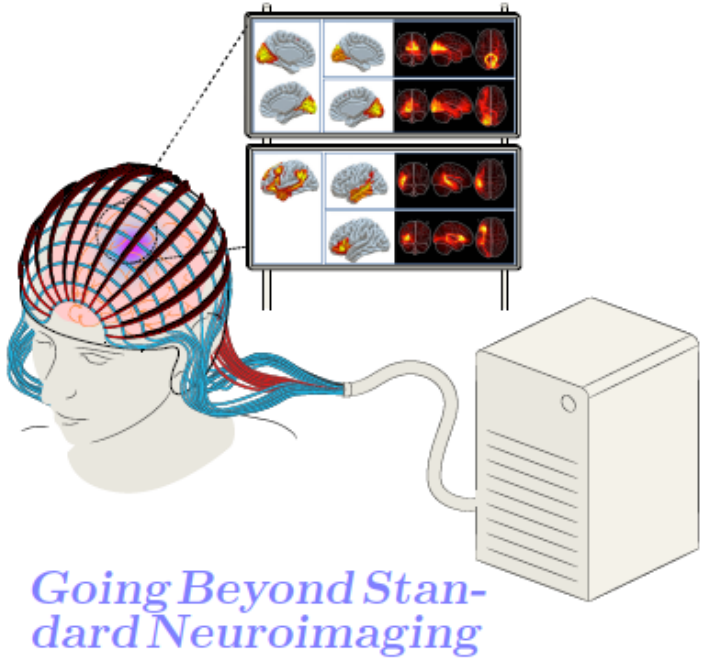
Eugene Polzik
Professor, Quantum Optics, NBI. Director, CBQS
Fundamental Physics
EXAAQ technology development since 2017
Academic research in optics, quantum, and atomic physics since 1990

Sensor Type III:

Atomic Magnetic Induction Tomography

Distant noninvasive detection of weakly conducting objects

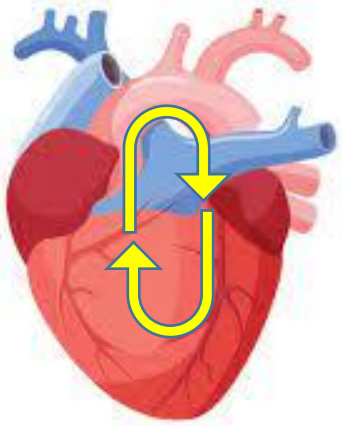




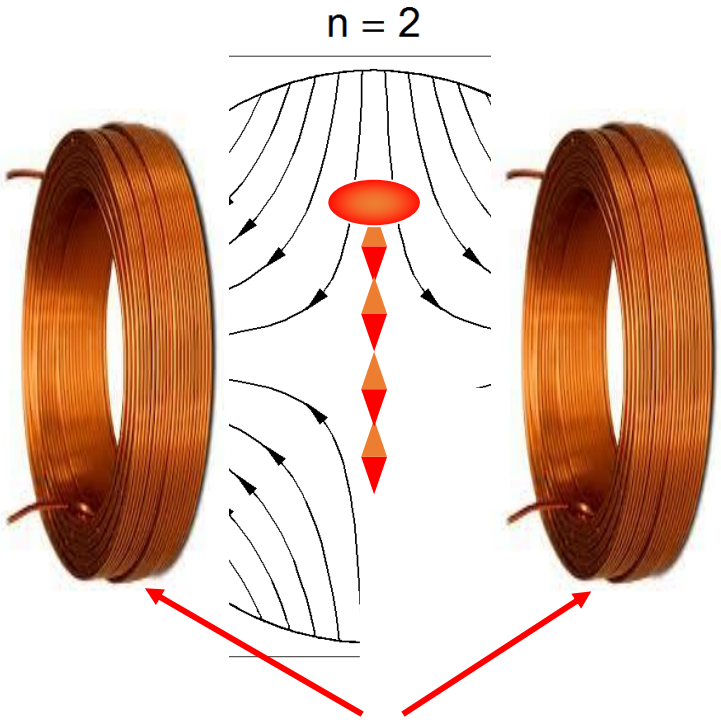
Sensor Type III:

Atomic Magnetic Induction Tomography (Atomic MIT)

Distant noninvasive detection of weakly conducting objects

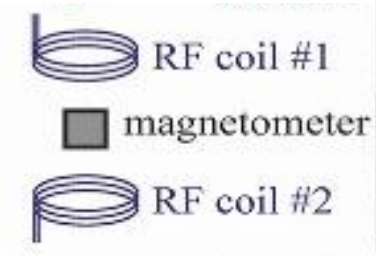


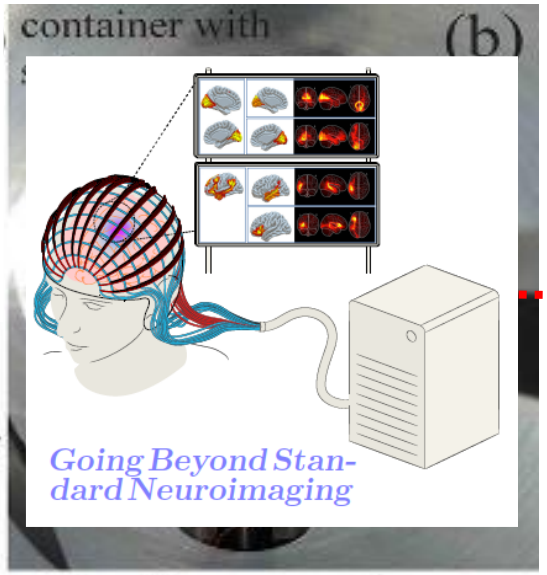
Induced currents

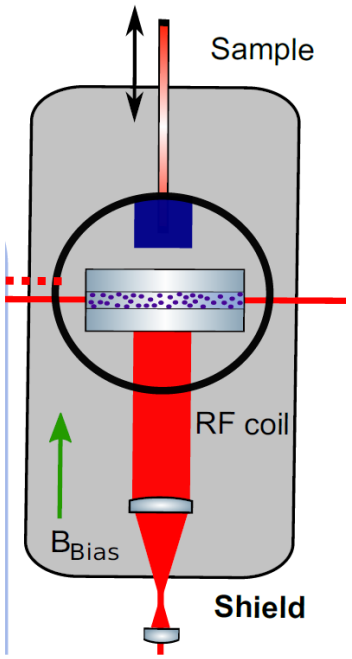


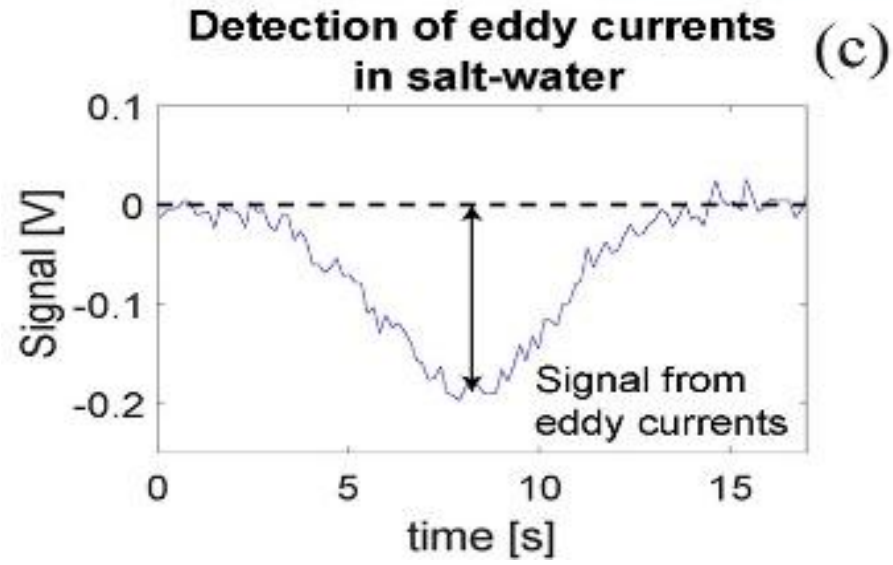
Anti-Helmholz coils

Atomic Magnetic Induction Tomography (Atomic MIT)
Towards brain/heart diagnostics via conductivity measurement





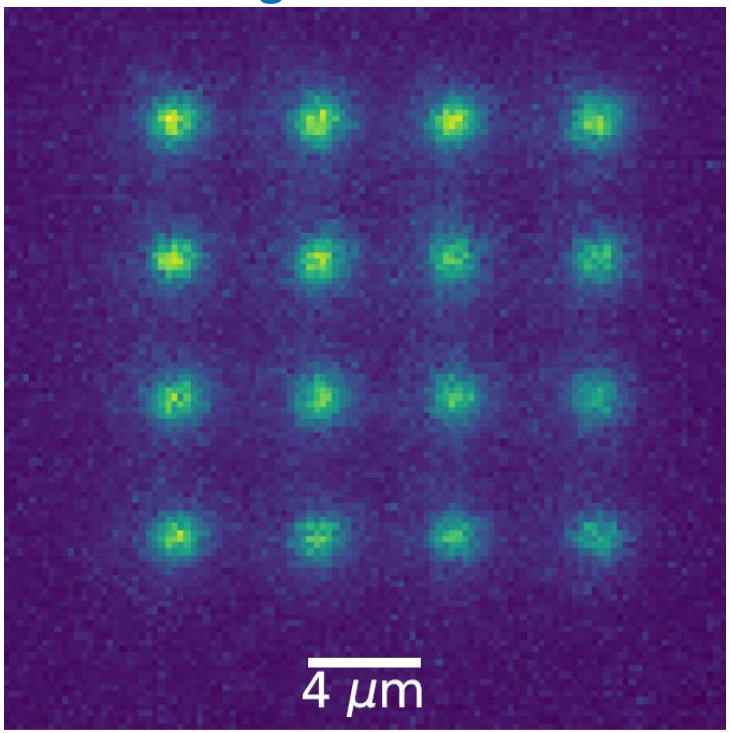




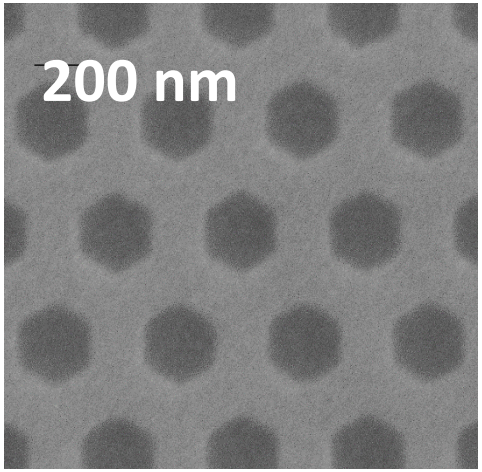
Goals:
Detection of brain, heart anomalies by noninvasive conductivity measurements

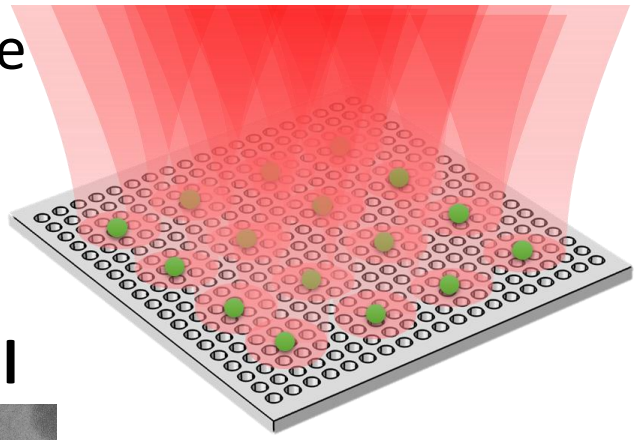
Perspective: sensing with ultracold atomic lattice

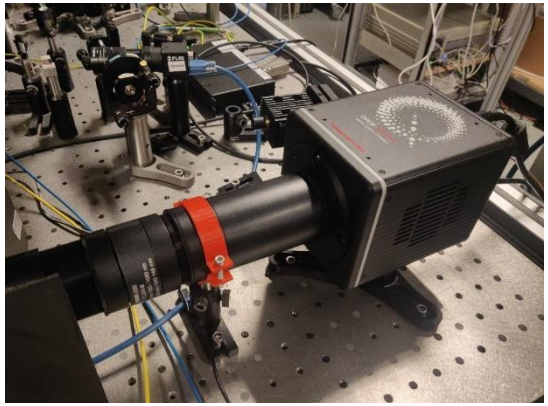
Caesium atoms trapped and cooled to near ground state of motion



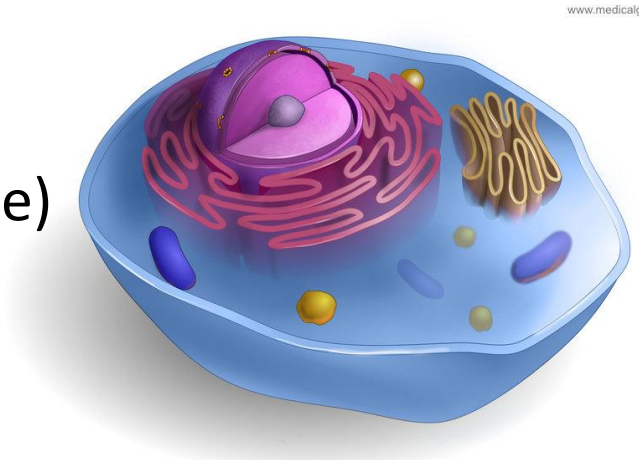
SiN 2D Photonic crystal







Cell (to scale)



Jean-Baptiste Béguin

Jörg Müller

Quantum Limits of Sensing
and beyond

Take home message:
there are no limits
for sensitivity to e.-m. fields
and forces


QUANTOP 2023
NovoNordisk Center for
Biomedical Quantum Sensing

Work packages and collaboration links