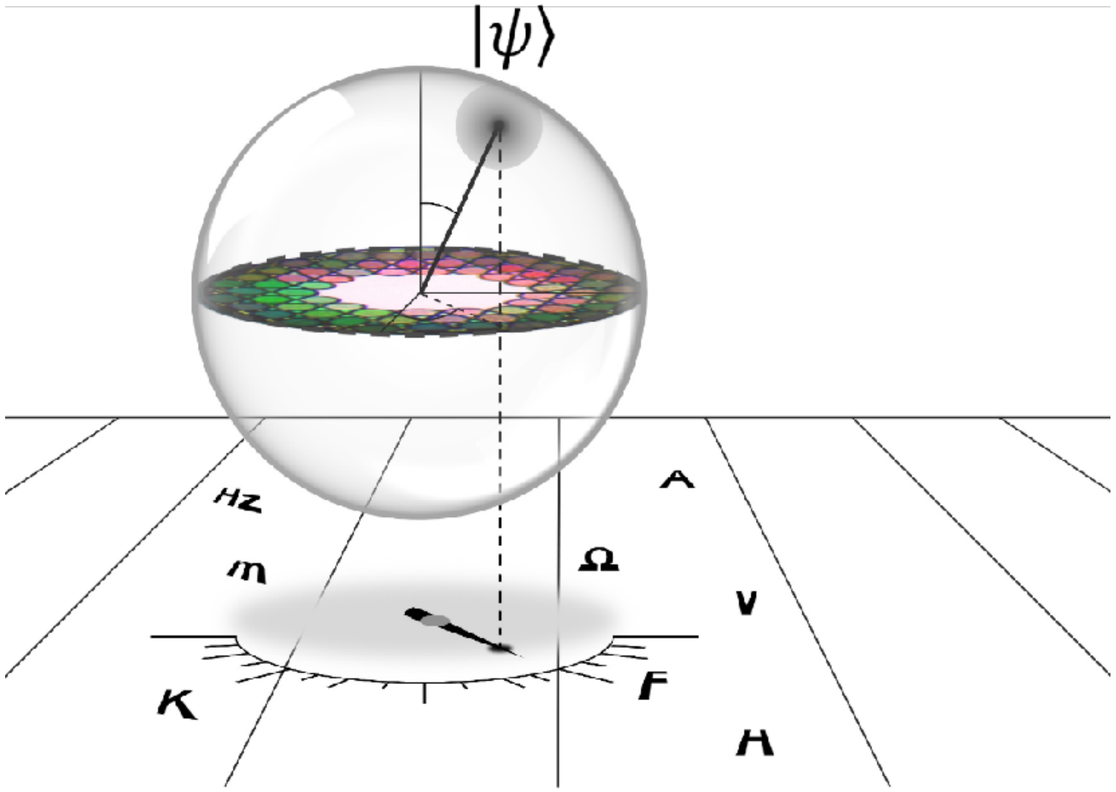
GLOphotonics

The Hollow-Core PCF & Photonic MicroCell™ company

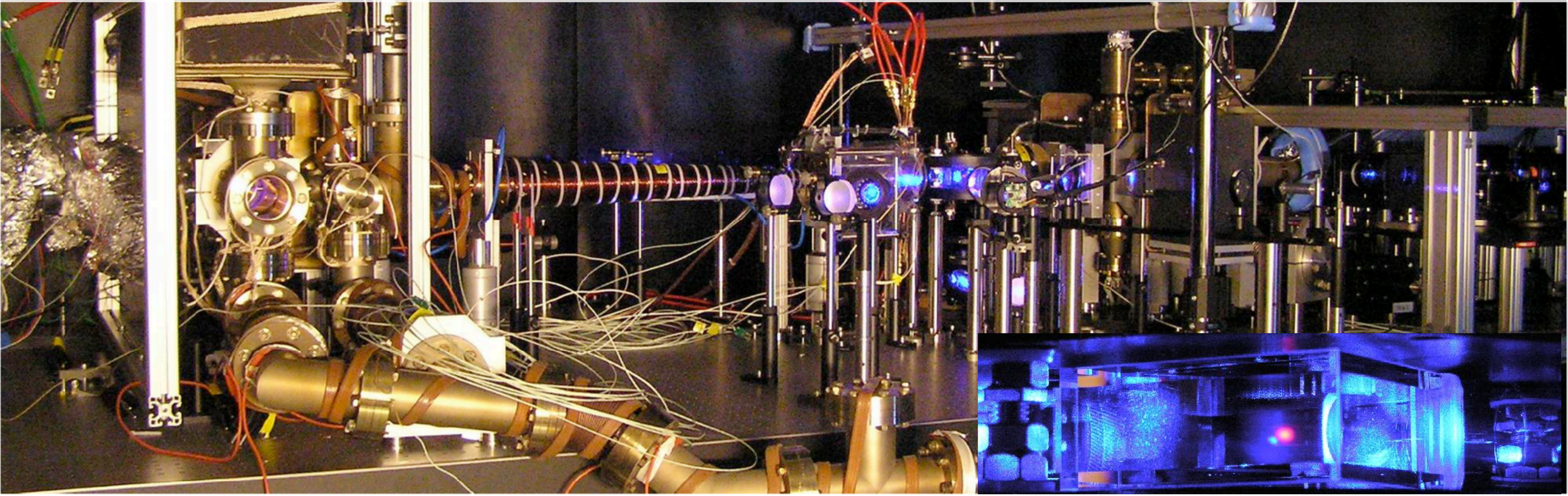
The Next Generation Quantum Sensing Platform

Devang Naik, Lead scientist, BTU QuTech

EPIC, October 12 (Munich, Germany)



Quantum Resources allow unheard of levels of sensitivities!!!



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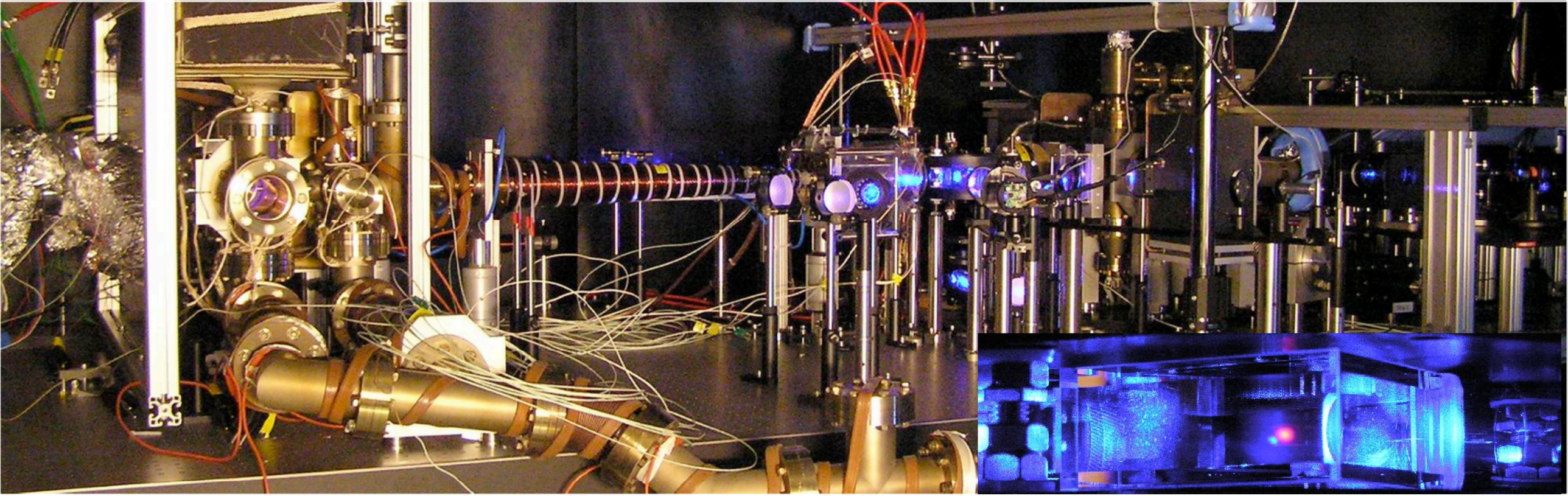
CONFIDENTIAL

Quantum Resources are remarkably Fragile !!!



need to be isolated from all sources of environmental noise:

- high vacuum systems: < 10^{-9} millibar

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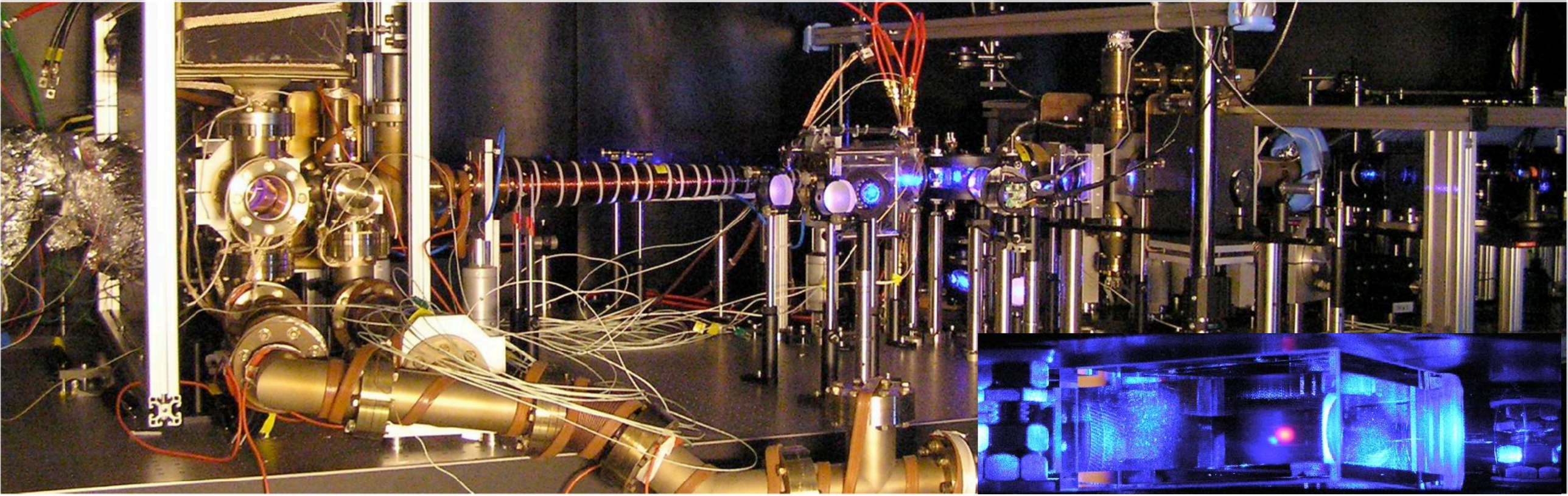

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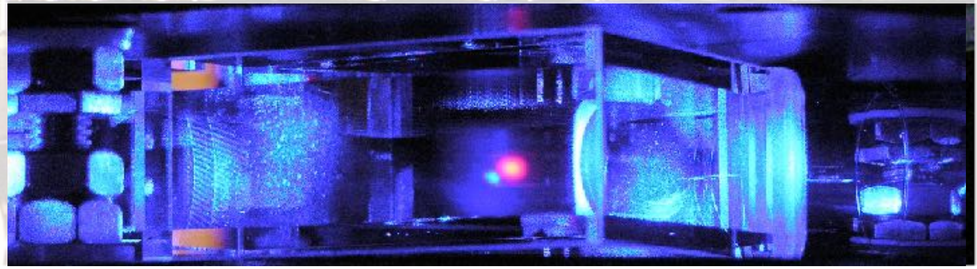
need for high atom-light interactions to create and control quantum resources

- ultra-cold temperatures - reduces effect of thermal motion



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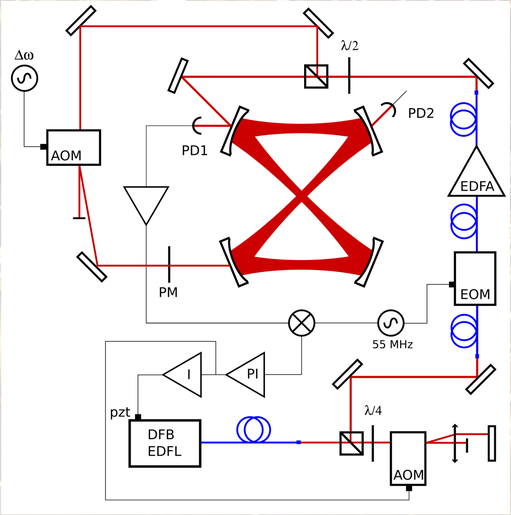

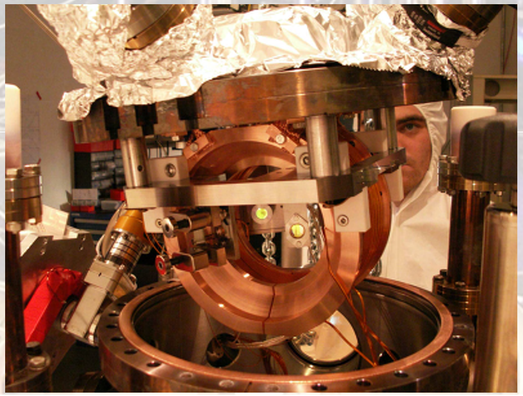

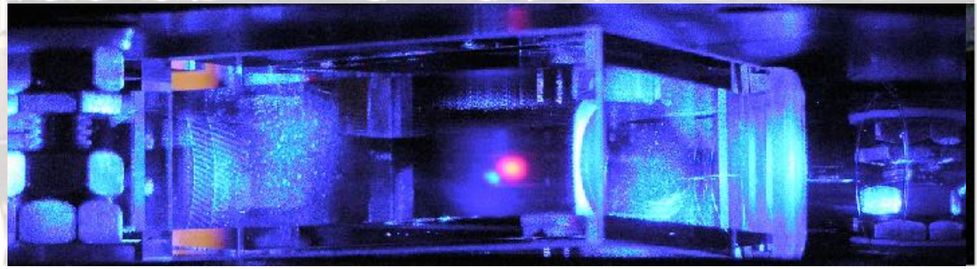

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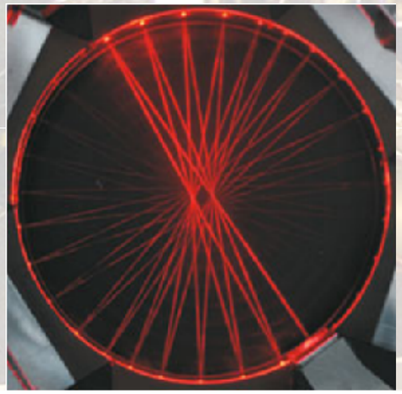
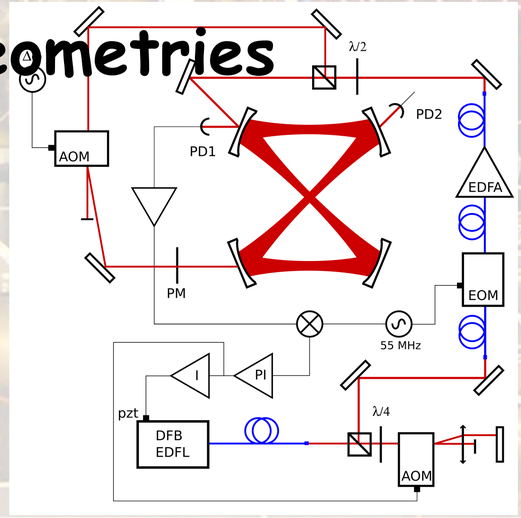
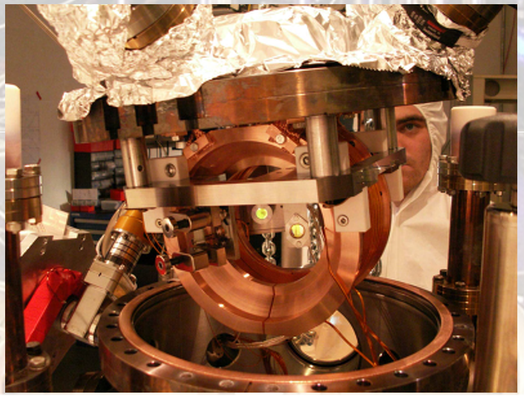
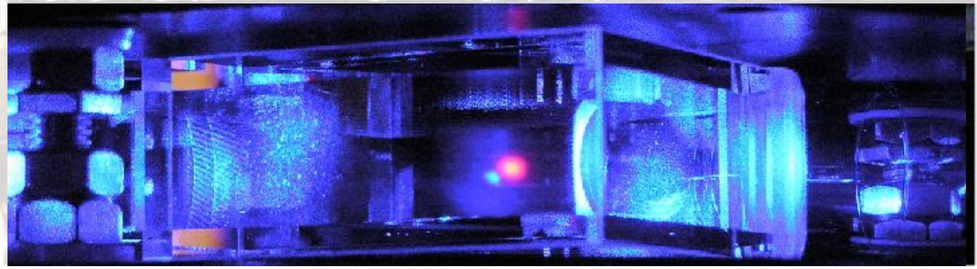
- multi-pass geometries









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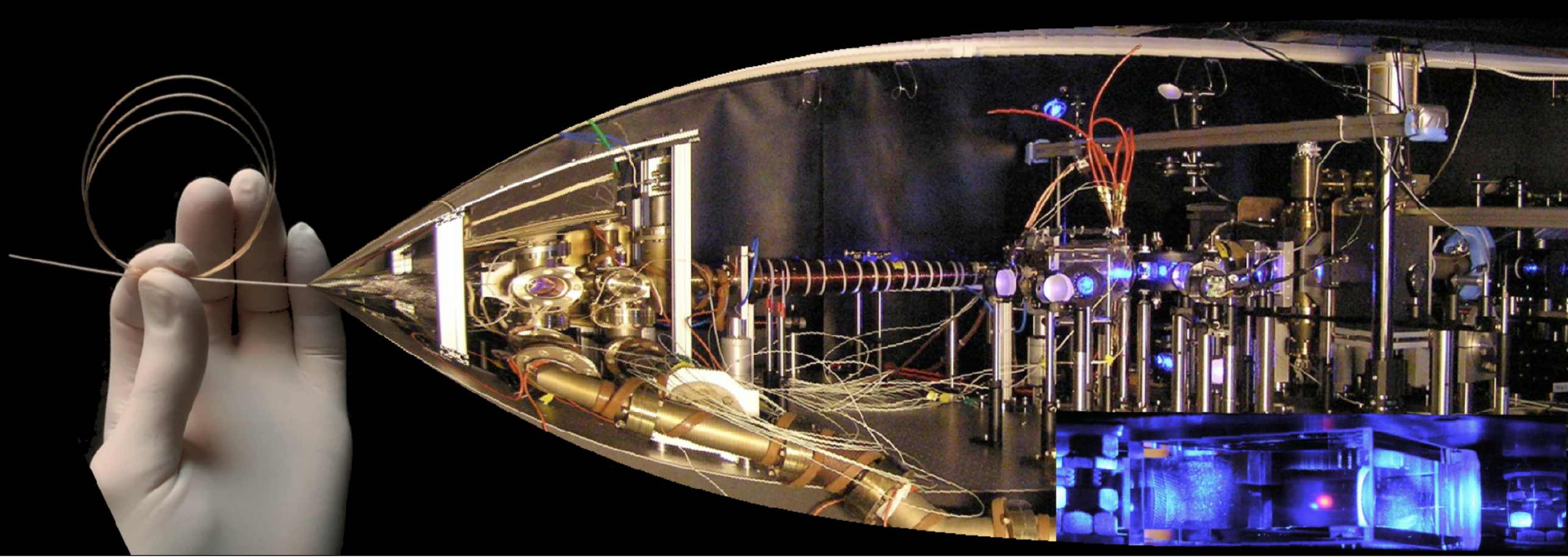

By confining light + atoms on length scales over kms, we can arrive at Orders of Magnitude Larger Atom-Light Interactions in a compact, simple platform with good vacuum

- volume reduced from m^3 to 100s um^3 !!!

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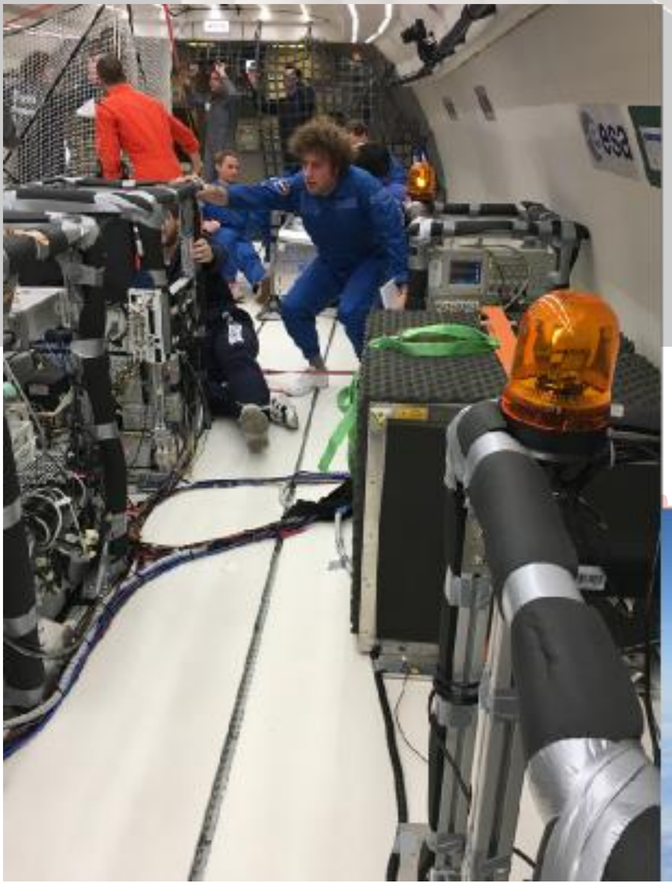
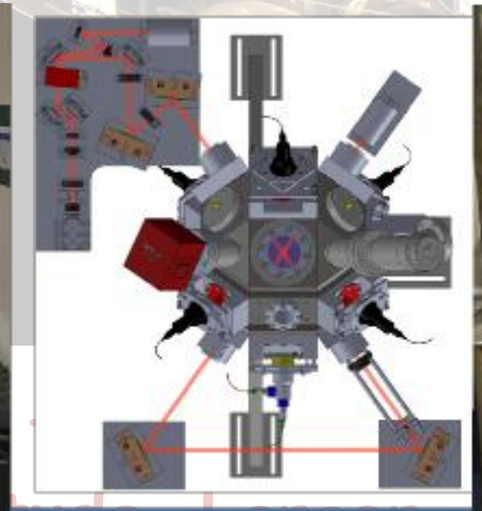
Minituarizing Quantum Technologies in Free Space

	Atom-Light Interaction	Coupling to Environment	Spectral Range	Vacuum (mBarr)	Compactness
Standard Free Space Technology	Limited by Light Dispersion	10^{-3}	visible	10^{-10}	m^3





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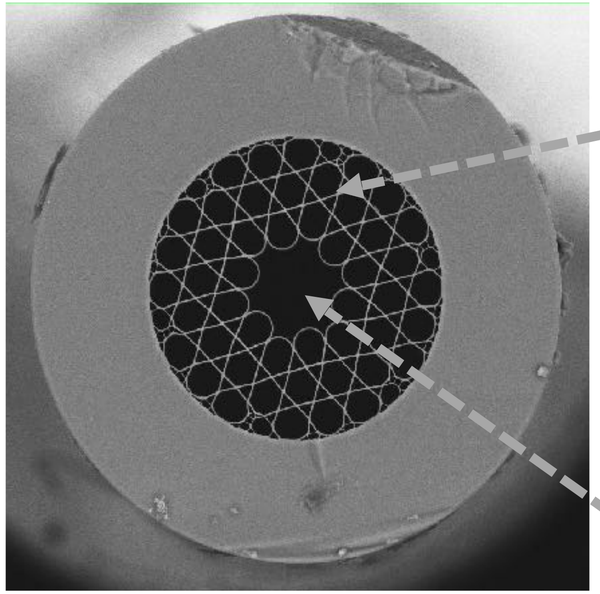
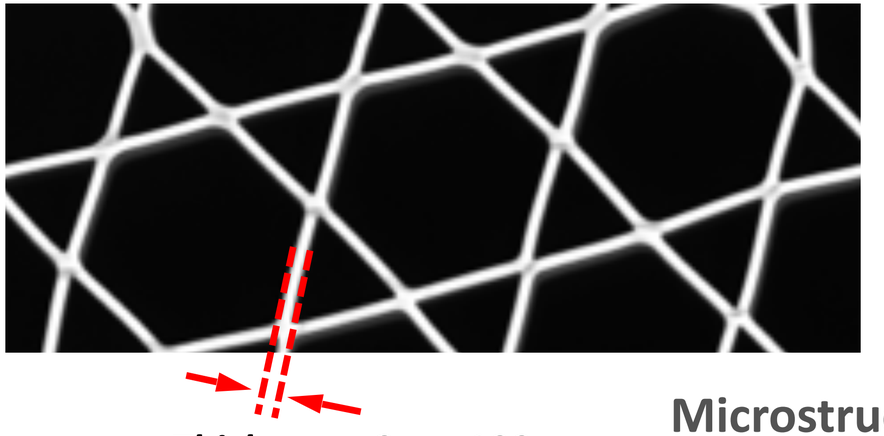
3 !!!

The Hollow Core Family

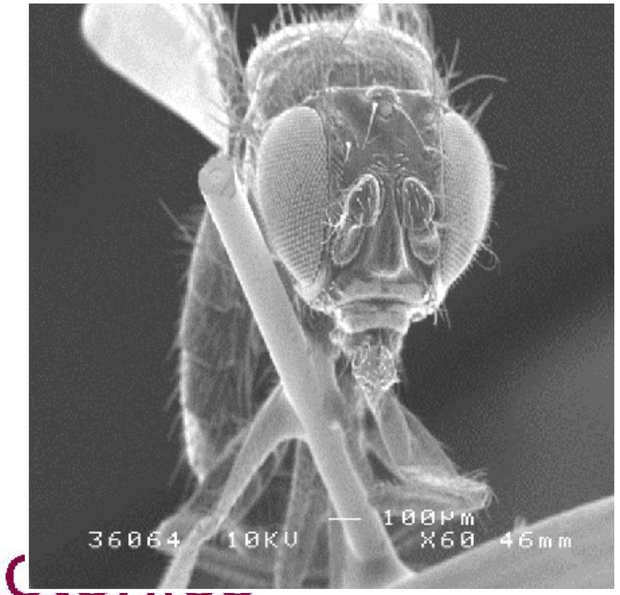




Thickness : 2µm-100nm

Microstructured Cladding (Air/Silica)

Hollow-core (5-150 µm)



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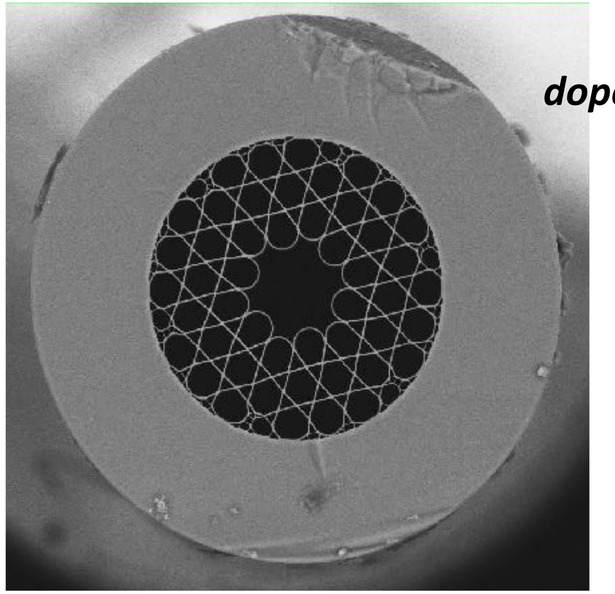
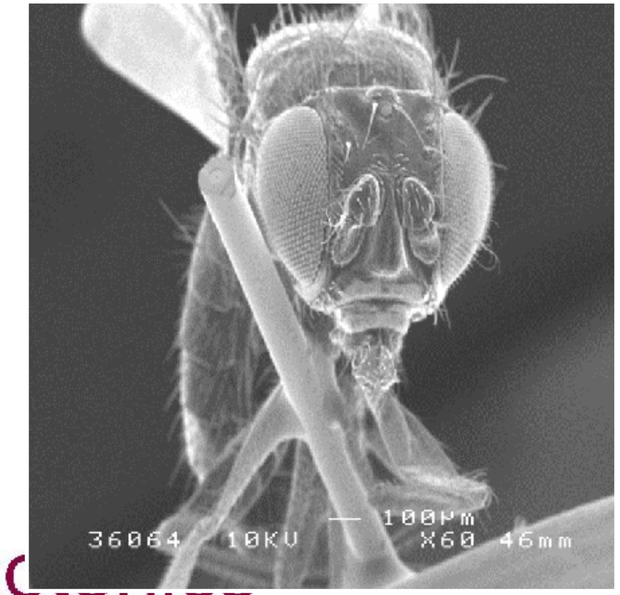
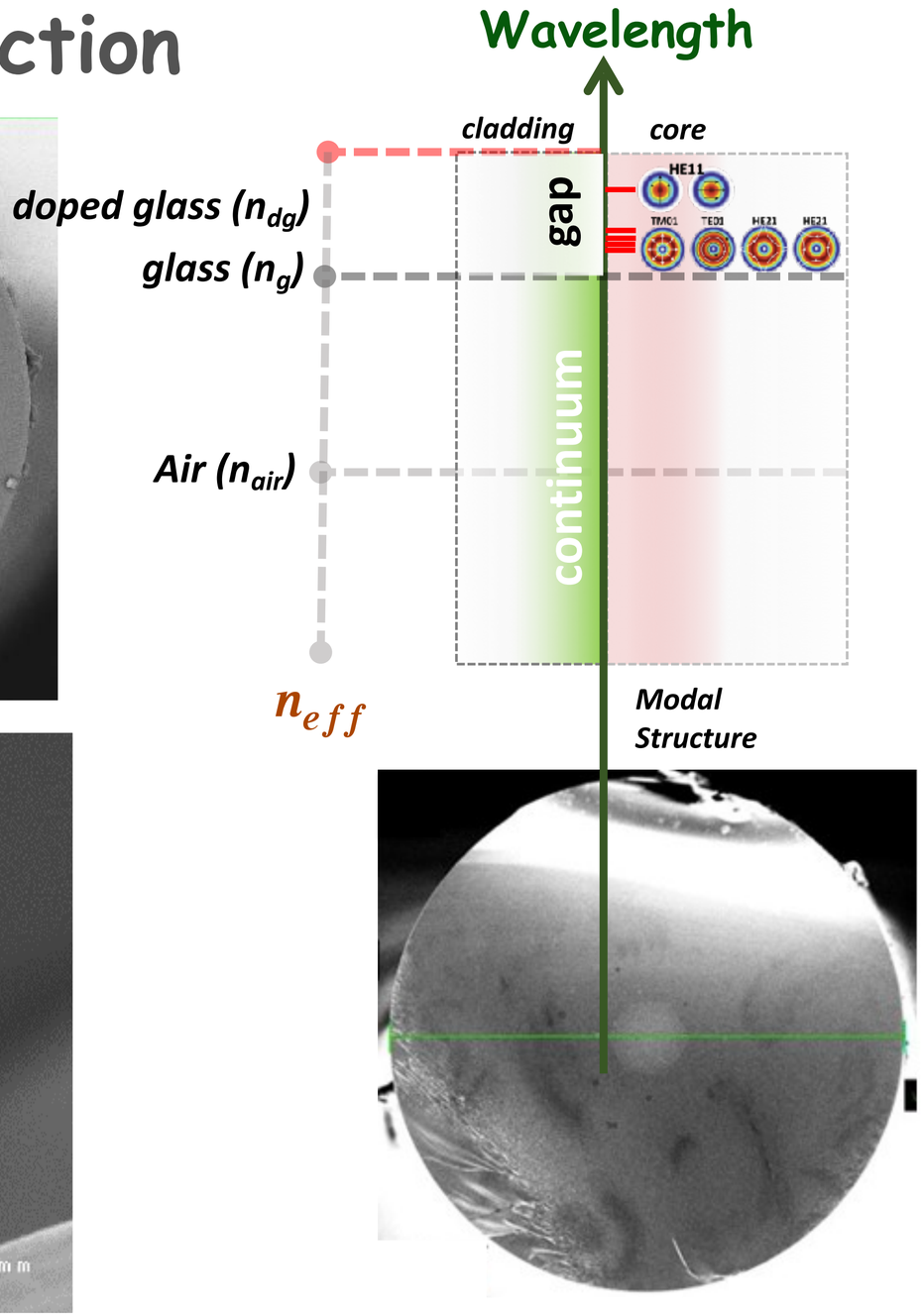
Total Internal Reflection



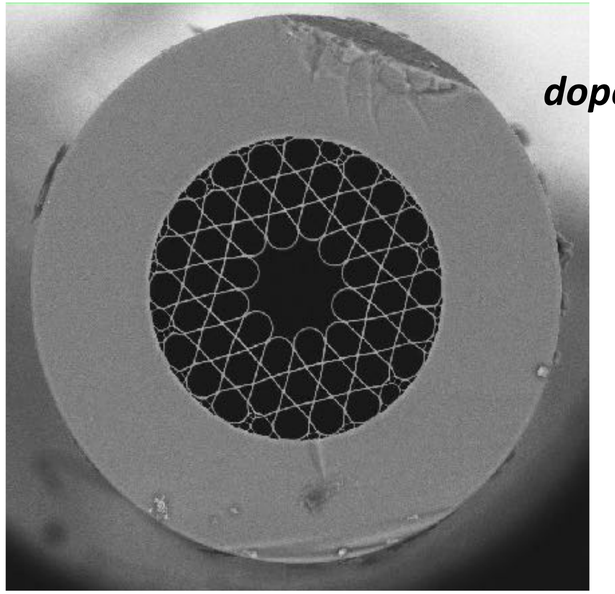


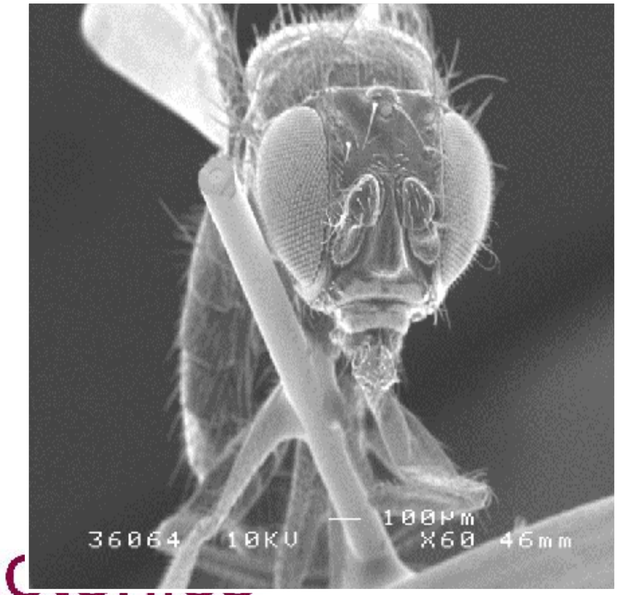


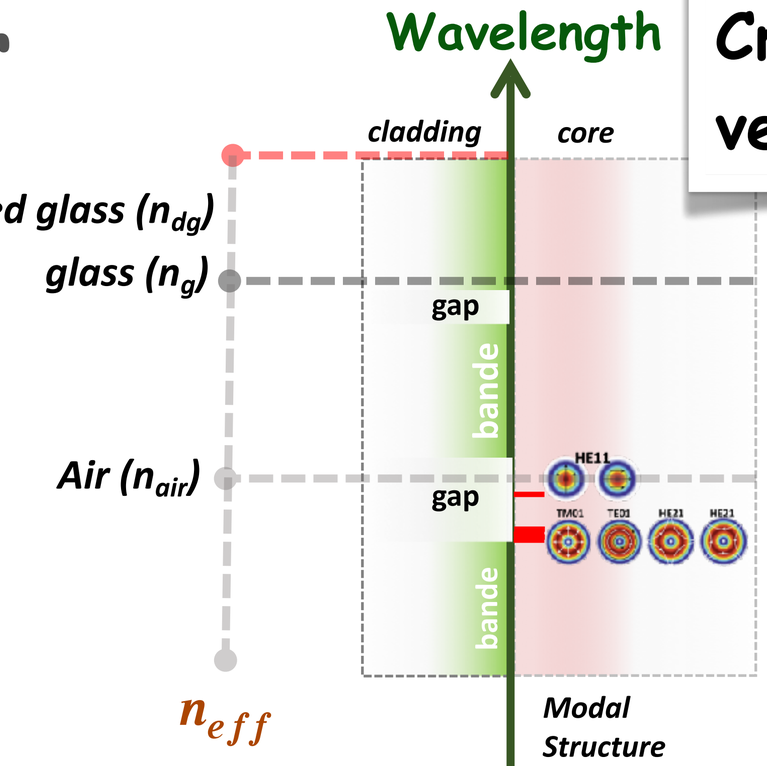
Solid-Core Fiber

Photonic Bandgap Fiber

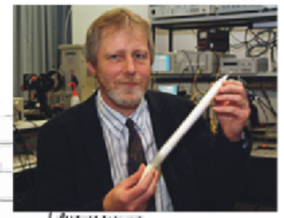
Create gaps in cladding at very particular wavelengths

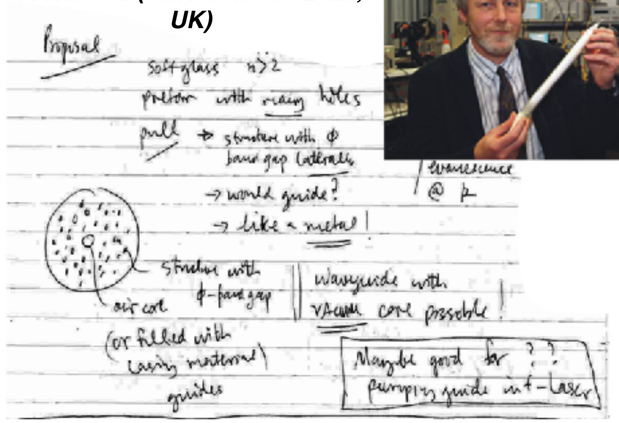


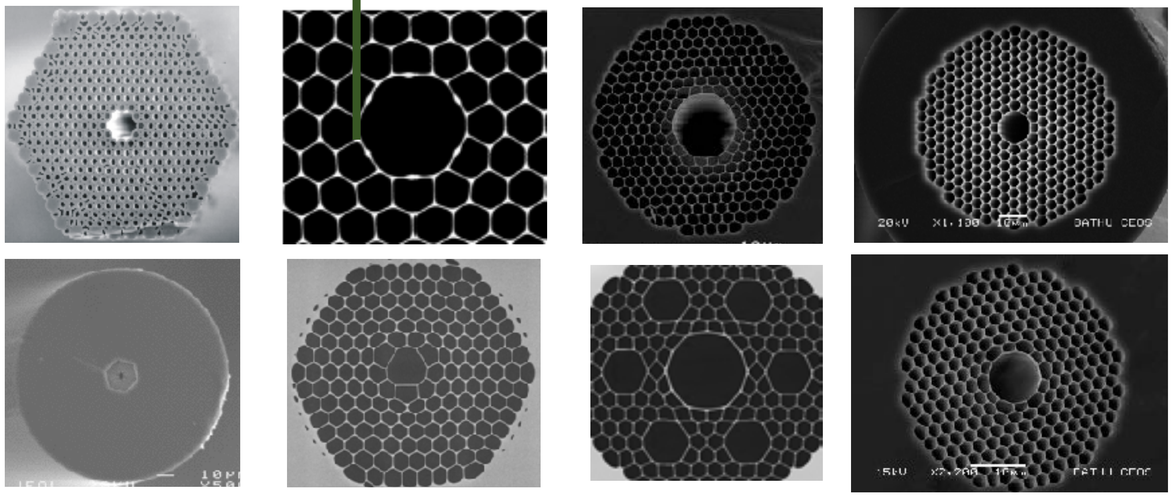




P. Russell (Université de Bath, UK)







Photonic bandgap guiding HCPCF

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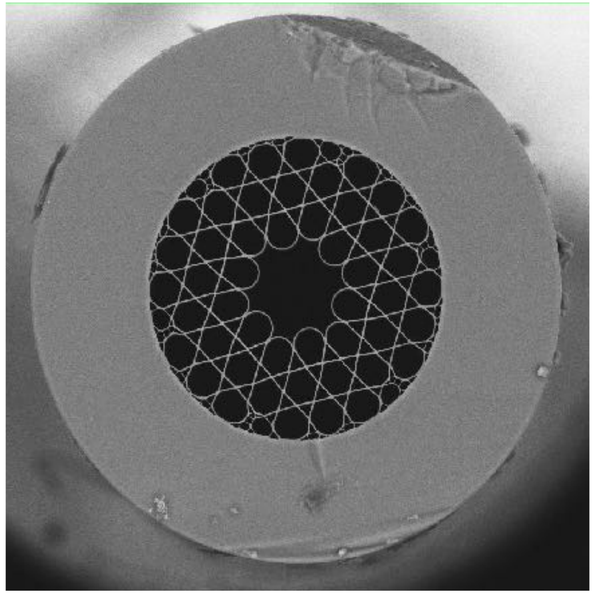
Inhibited Coupling



J. von Neumann

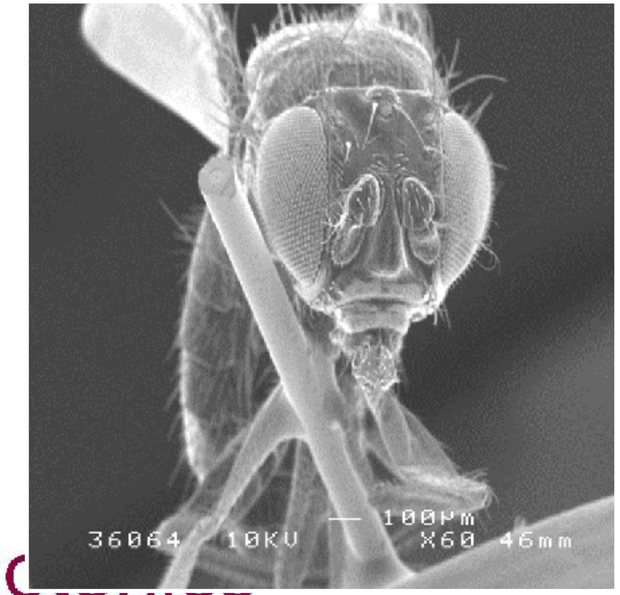
E.P. Wigner

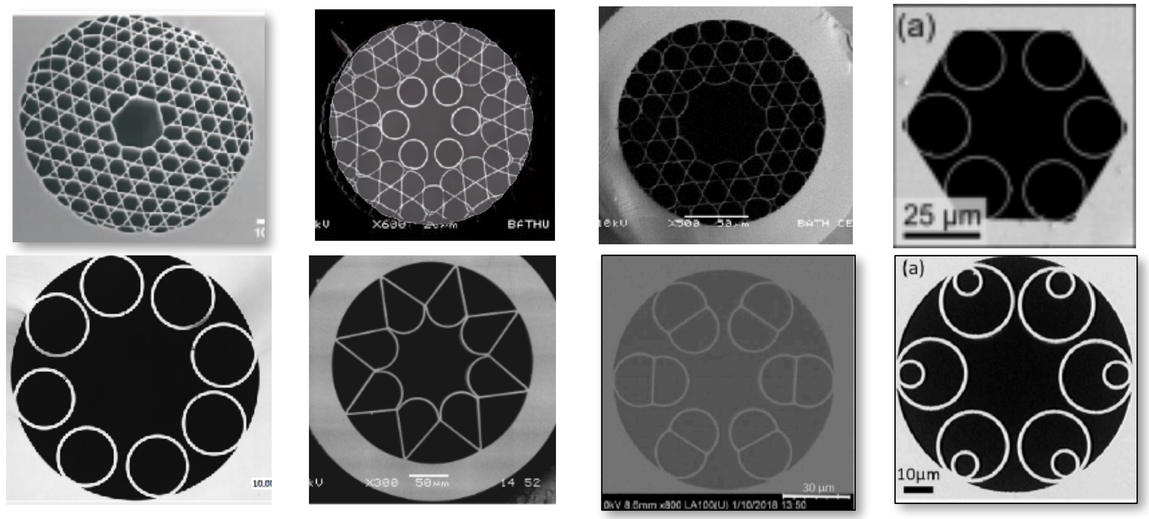
Über merkwürdige diskrete Eigenwerte

J. von Neumann and E. P. Wigner

Physikalische Zeitschrift *30*, 465–467 (1929)

Bounds States in the Continuum





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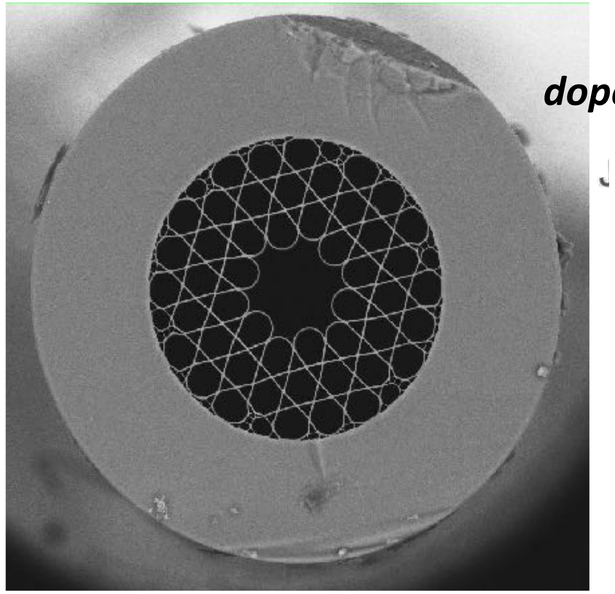

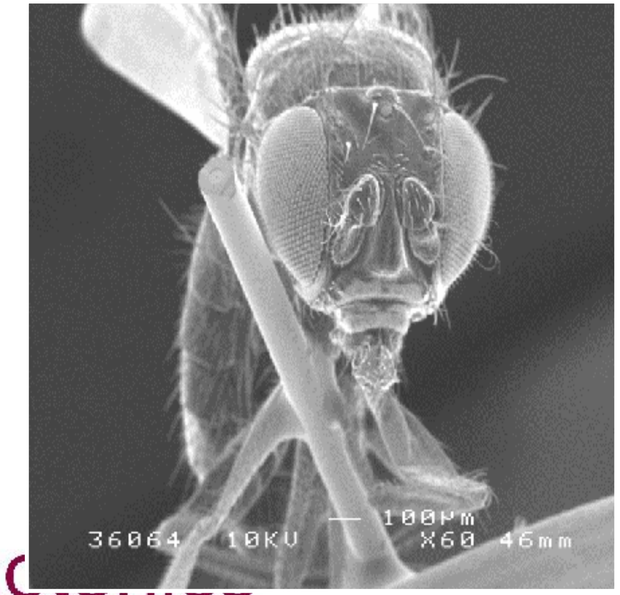

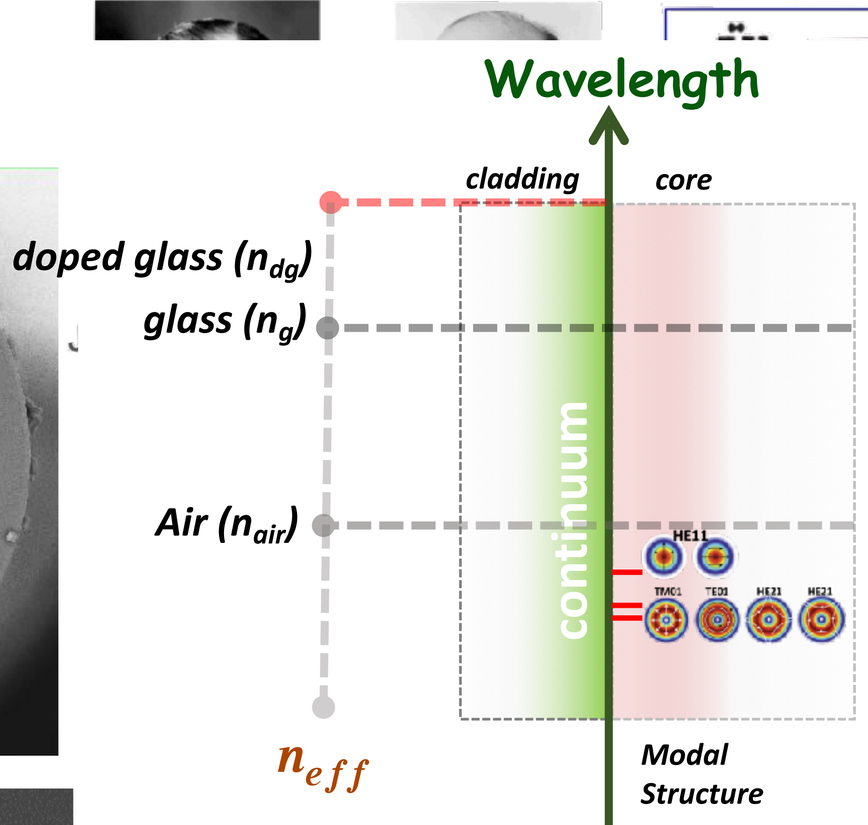

kwürdige diskrete Eigenwerte

on Neumann and E. P. Wigner

kalische Zeitschrift *30*, 465–467 (1929)

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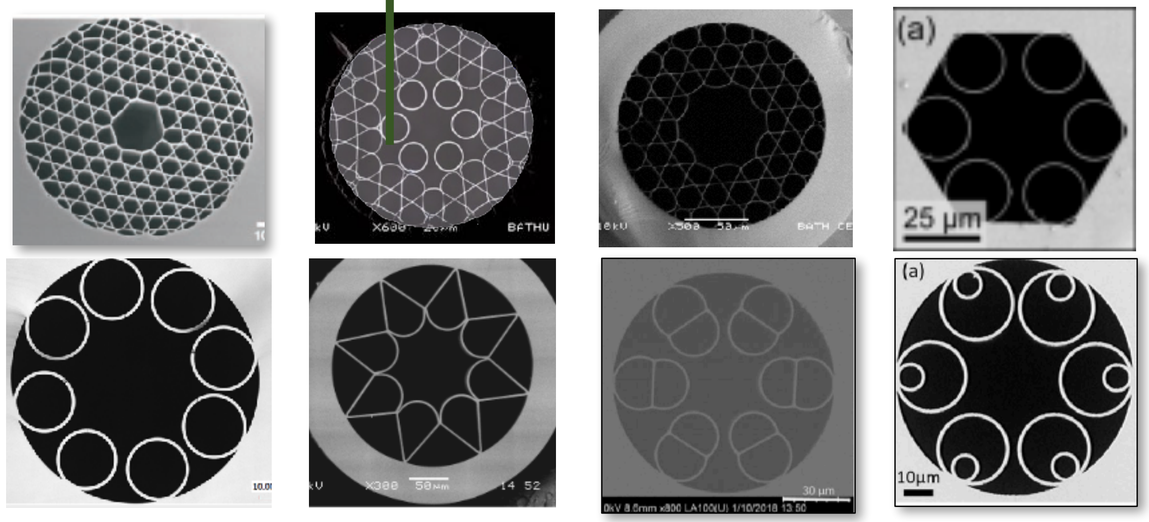

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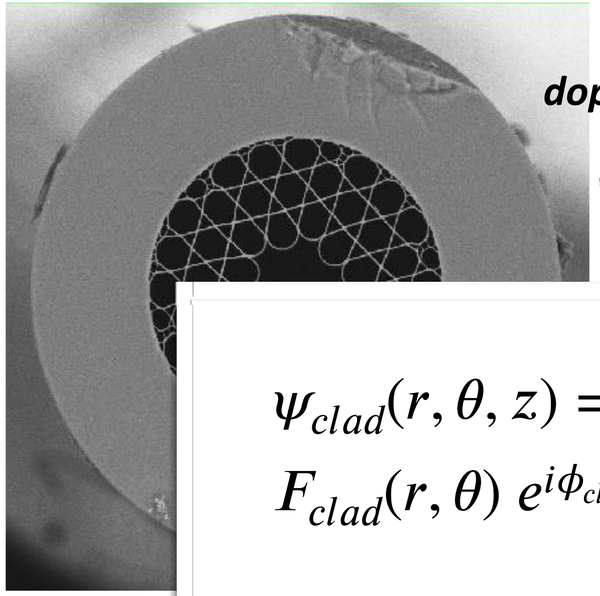

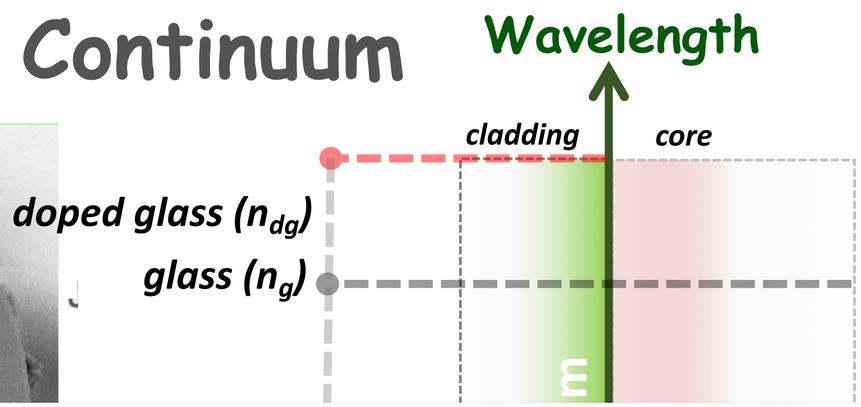

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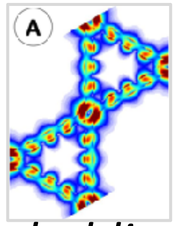
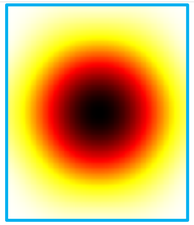


cladding



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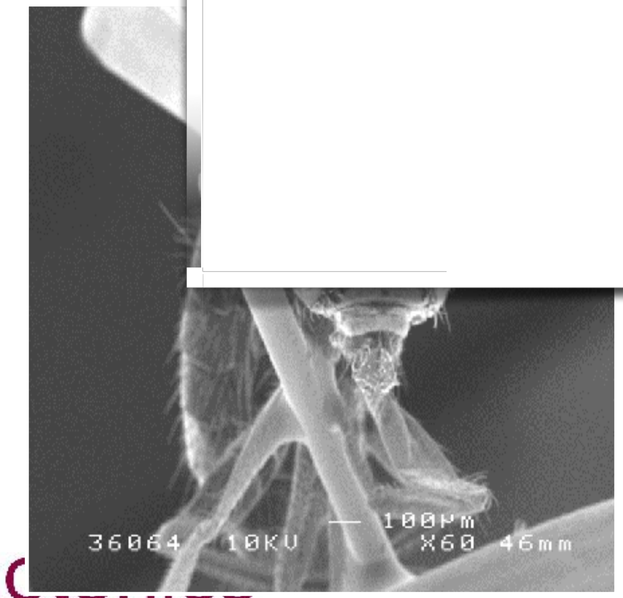

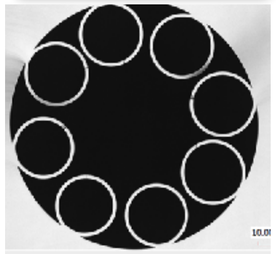

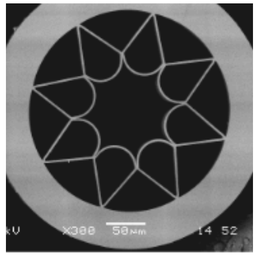

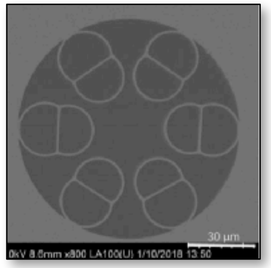

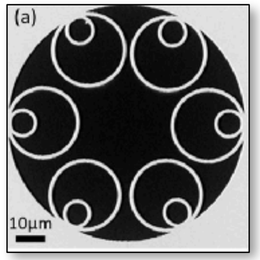

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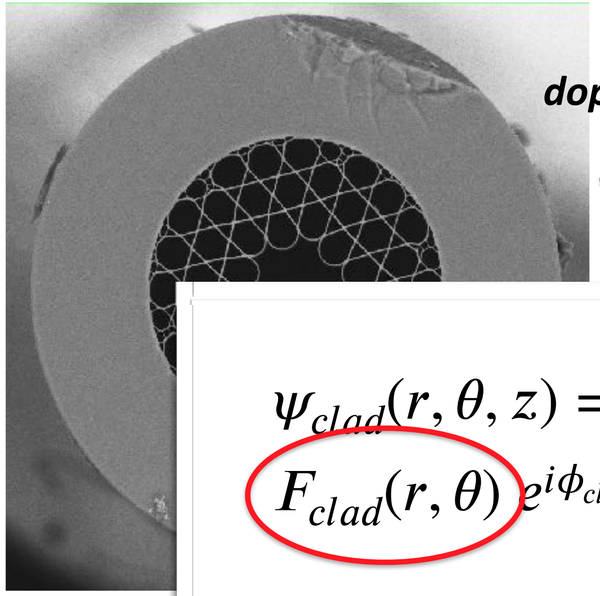
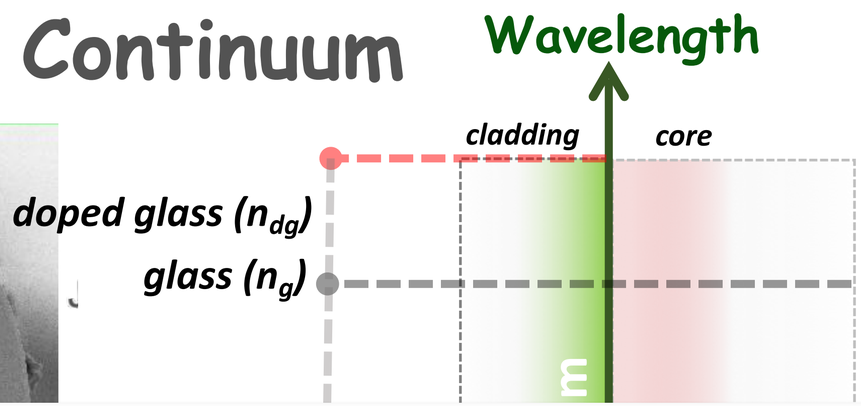
Bound States in the Continuum





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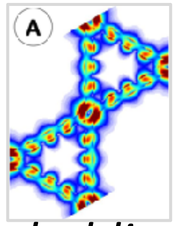

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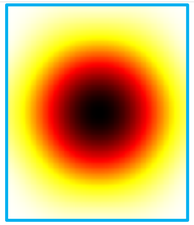

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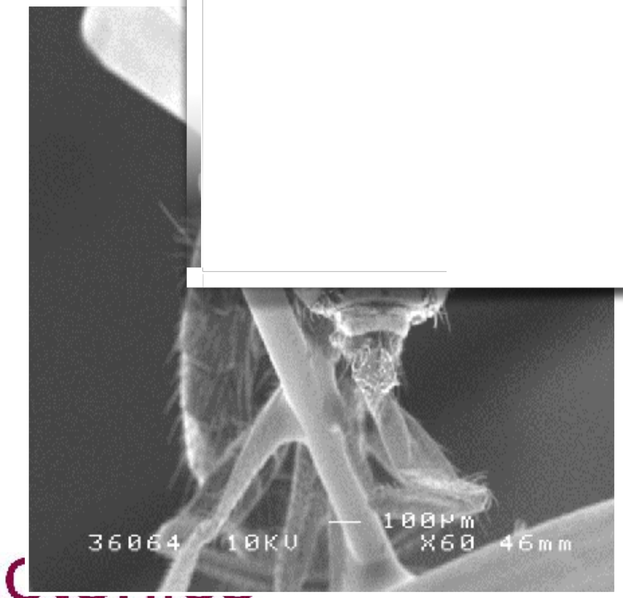
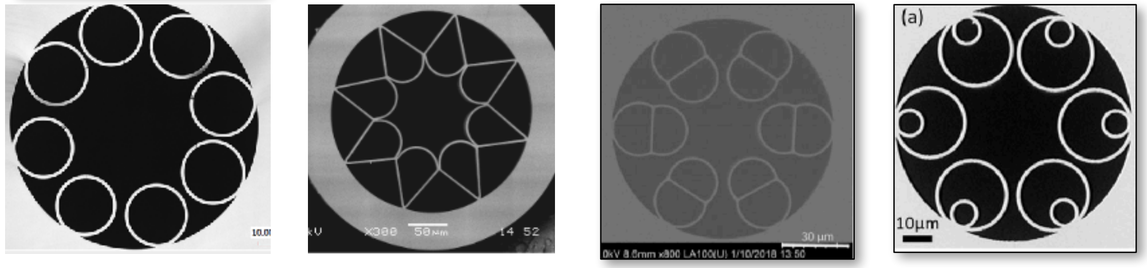
Amplitude





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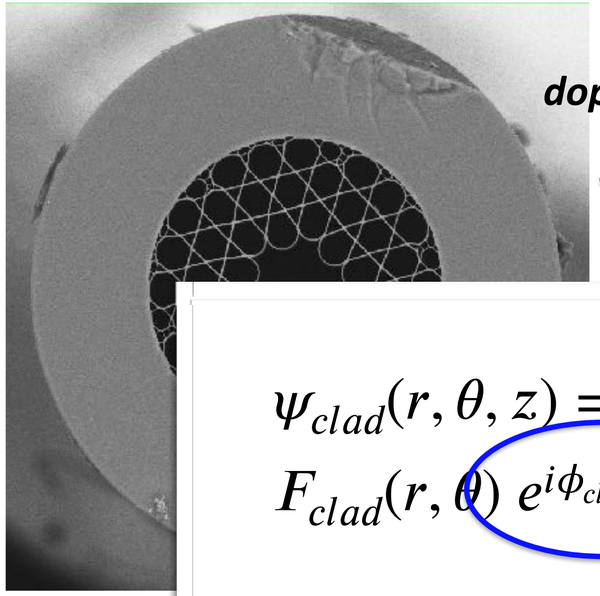

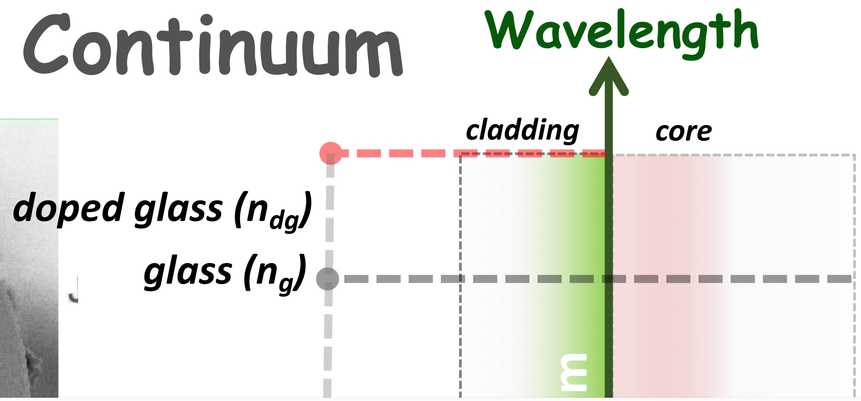

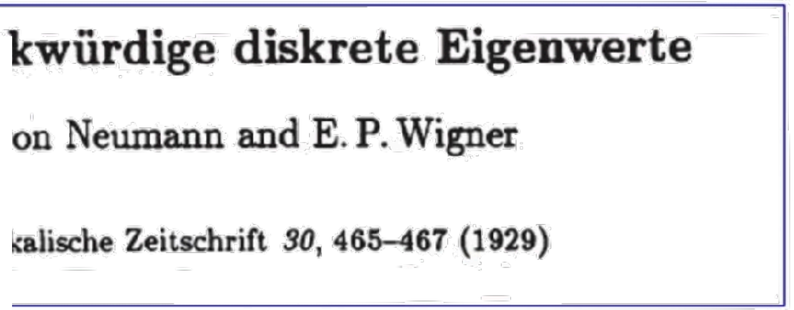
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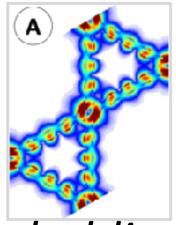
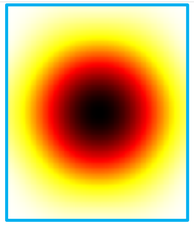


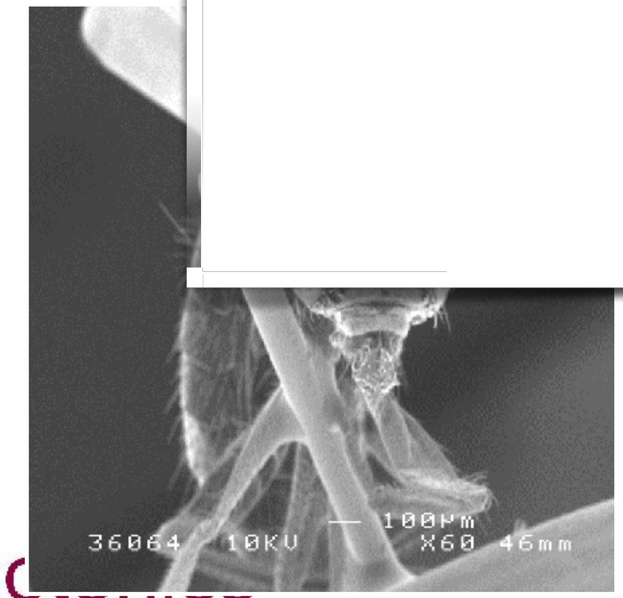
cladding

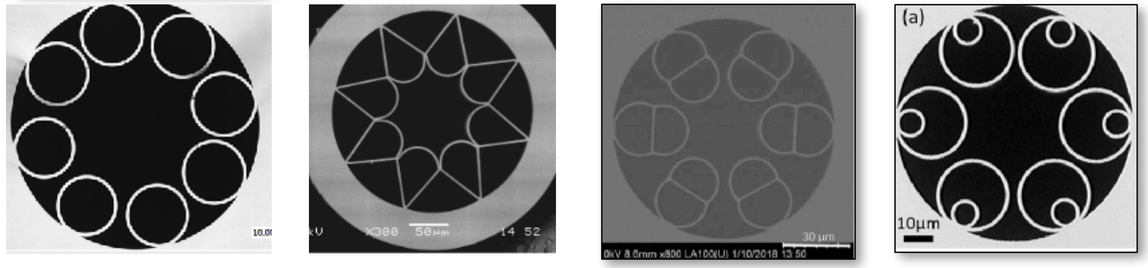


core

$$\psi_{core}(r,\theta,z) = F_{core}(r,\theta)\, e^{i\phi_{core}(r,\theta)}\, e^{i\beta z}$$

Phase

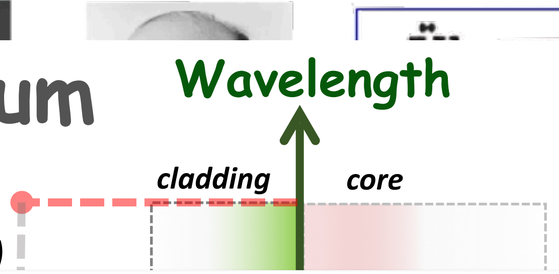




Inhibited-coupling guiding HCPCF

GLOphotonics
The Hollow-Core PCF & Photonic MicroCell™ company

Bound States in the Continuum



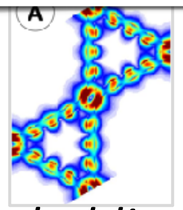
kwürdige diskrete Eigenwerte

on Neumann and E. P. Wigner

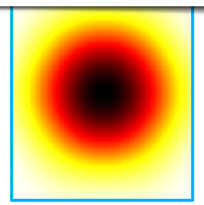
kalische Zeitschrift *30*, 465–467 (1929)

Phase Discontinuity leads to Zero Overlap between Core and Cladding

$$\psi_{clad}(r,\theta,z) = F_{clad}(r,\theta)\, e^{i\phi_{clad}(r,\theta)}\, e^{i\beta z}$$



cladding

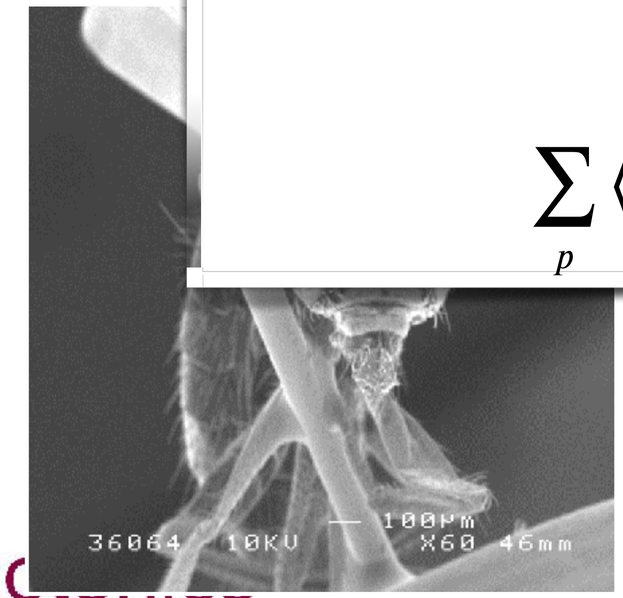


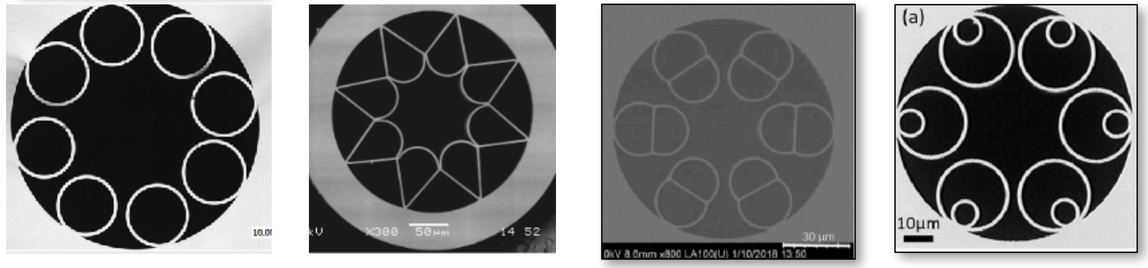
core

$$\psi_{core}(r,\theta,z) = F_{core}(r,\theta)\, e^{i\phi_{core}(r,\theta)}\, e^{i\beta z}$$

$$\langle \psi_{core} | \Delta n^2 | \psi_{clad} \rangle \to 0$$

$$\sum_p \langle F_{clad}(r) | a_p(r) | F_{core}(r) \rangle \langle e^{im_{clad}\theta} | e^{ip\theta} | e^{im_{core}\theta} \rangle$$





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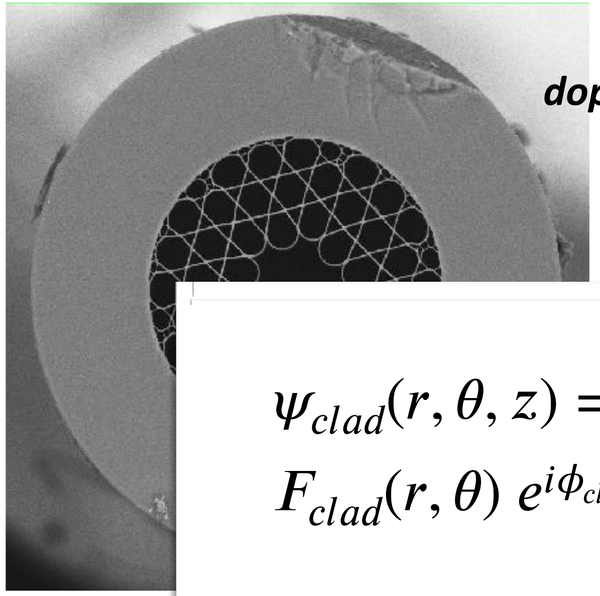

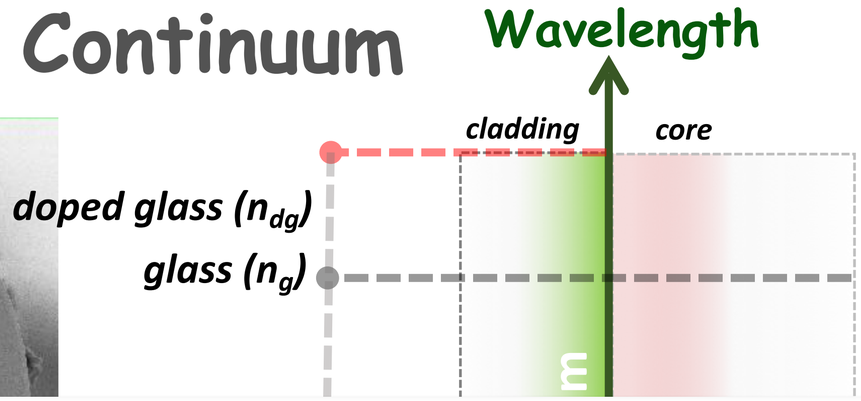

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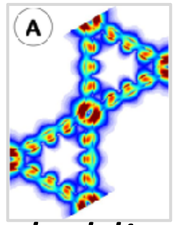
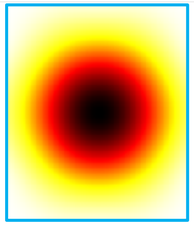


cladding



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	Atom-Light Interaction	Coupling to Environment	Spectral Range	Vacuum (mBarr)	Compactness
Standard Free Space Technology	Limited by Light Dispersion	10^{-3}	visible	10^{-10}	m^3
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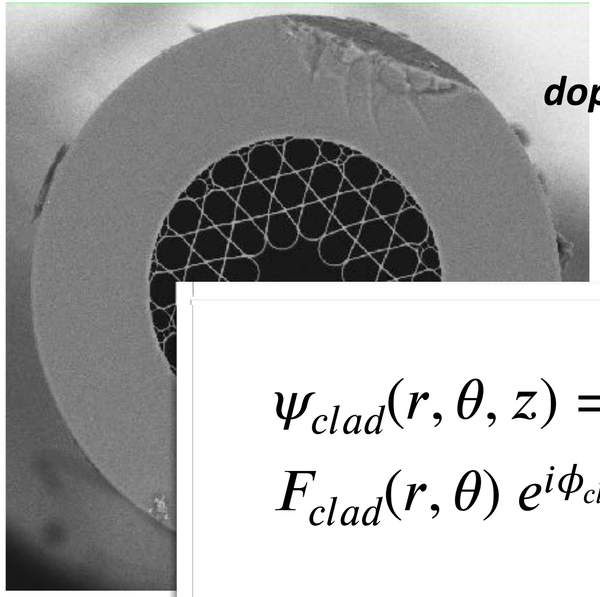
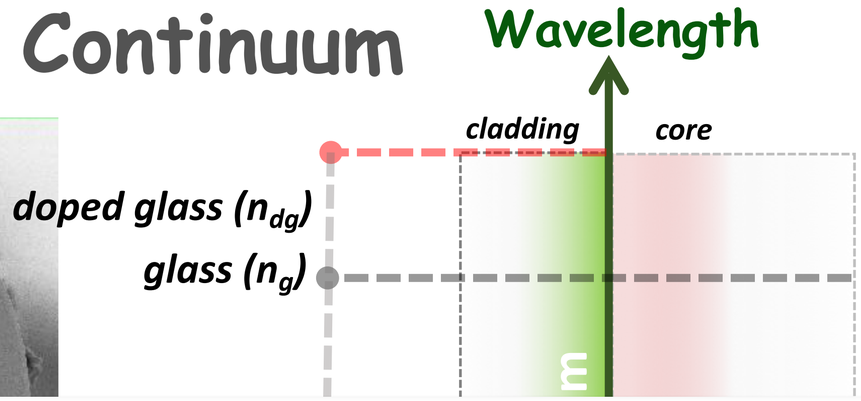
Bound States in the Continuum





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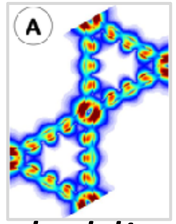
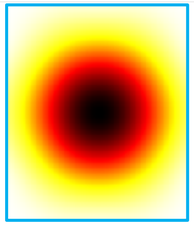


cladding



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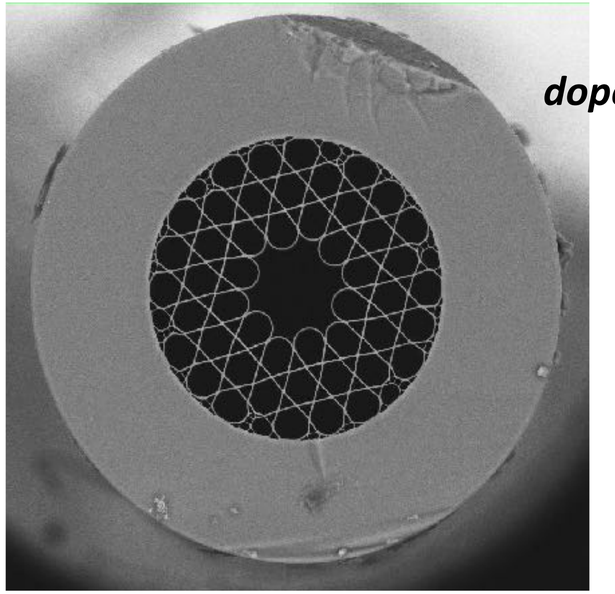
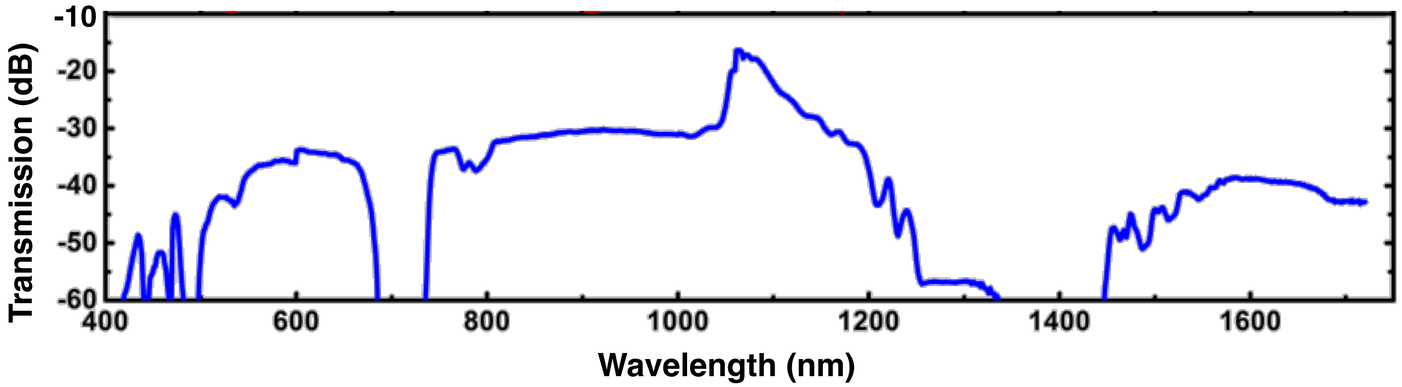
Bound States in the Co

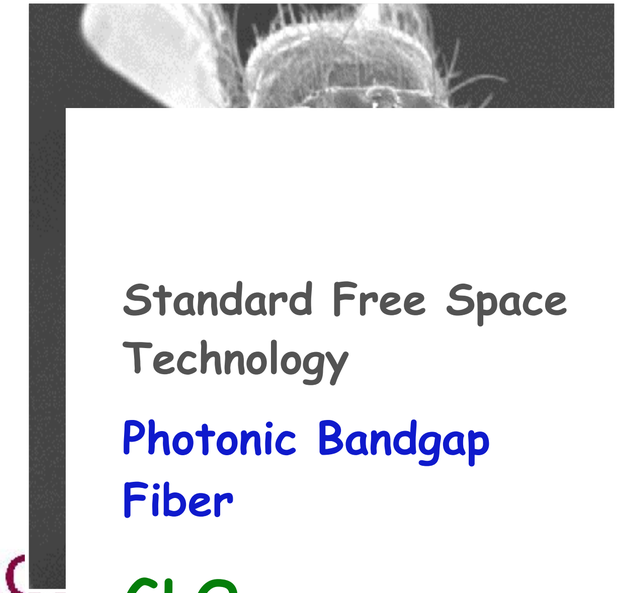


doped

Large Spectral Domain !!!



Crucial for Quantum Technologies involving Exotic Atoms or NV Centers



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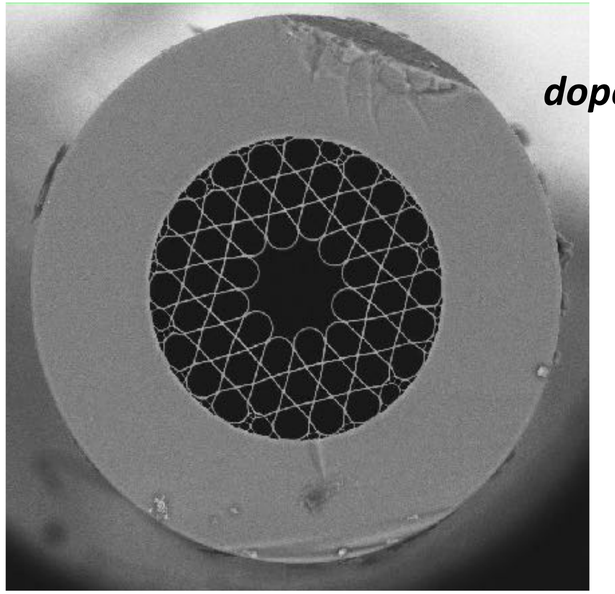
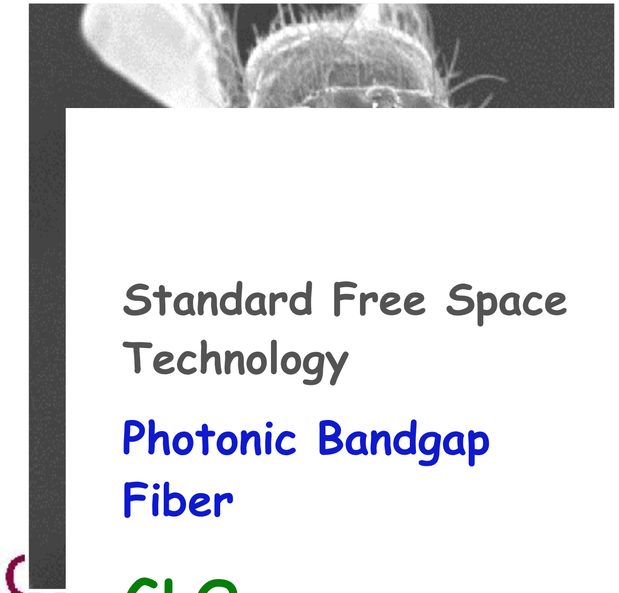
GLOphc
The Hollow-Core PCF

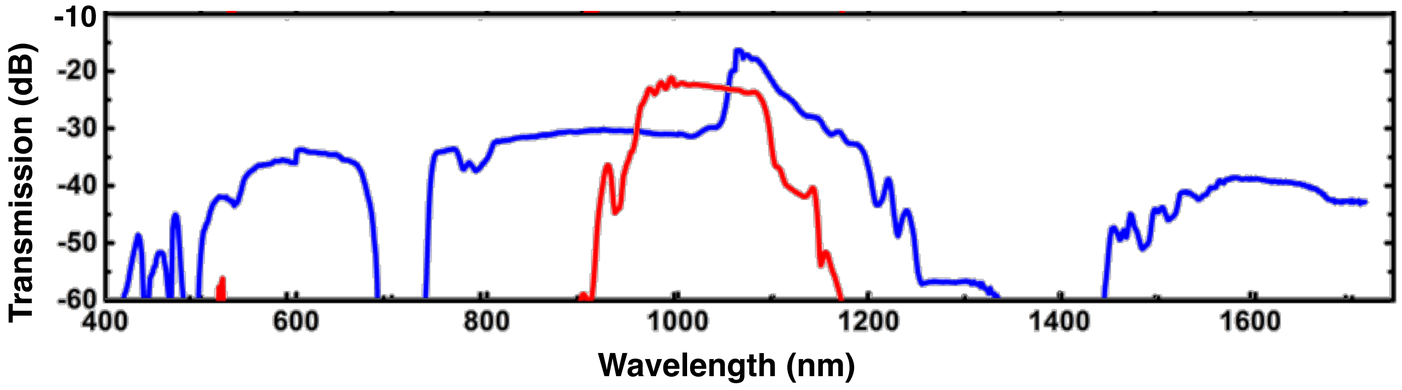
Bound States in the Co



doped



Large Spectral Domain !!!



Much larger Domain with respect to Photonic Bandgap or Free Space

	Atom-Light Interaction	Coupling to Environment	Spectral Range	Vacuum (mBarr)	Compactness
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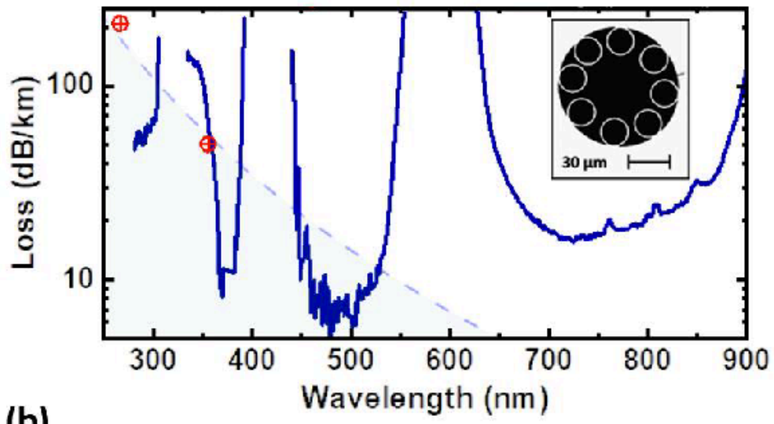
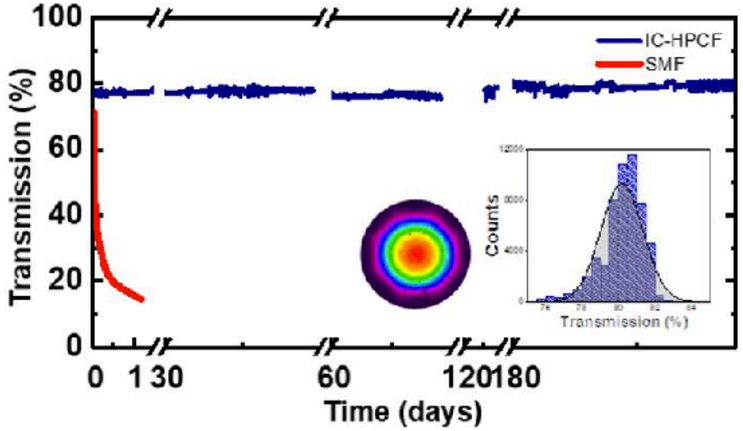
Transmission in UV



(b)



Large Spectral Domain !!!

Potential for Extreme UV transmission: advantage of vacuum in fiber core

The Only Company in World offering solutions in Deep-UV

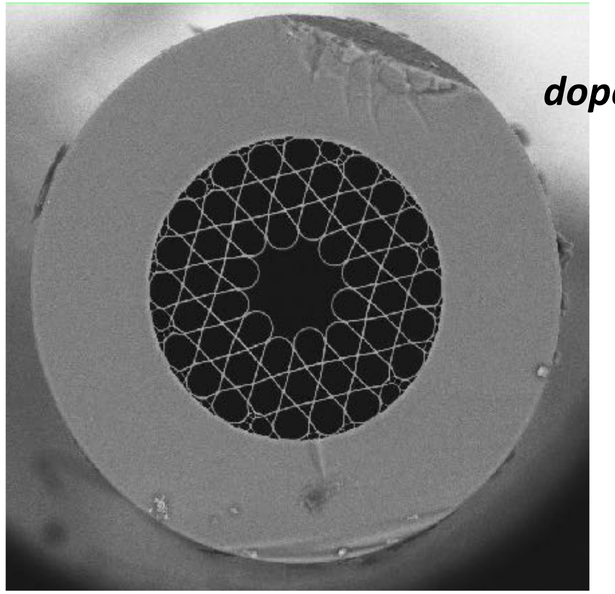
- UV-based tumor surgery
- Thorium Atomic Clocks

Standard Free Spa
Technology

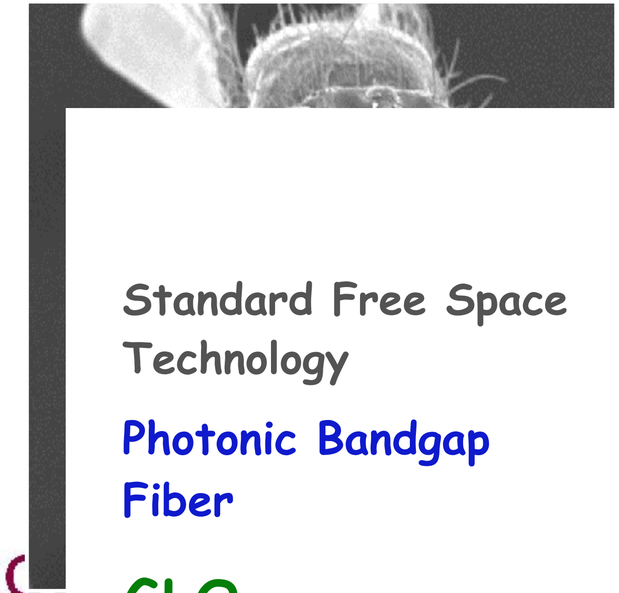
Photonic Bandgap
Fiber

GLO

Bound States in the Co



doped



Large Decoupling of Light to Surrounding !!!

10^{-6} wavefunction overlap between core and cladding/environment

Decouples Atom-Light interactions from environmental noise

	Atom-Light Interaction	Coupling to Environment	Spectral Range	Vacuum (mBarr)	Compactness
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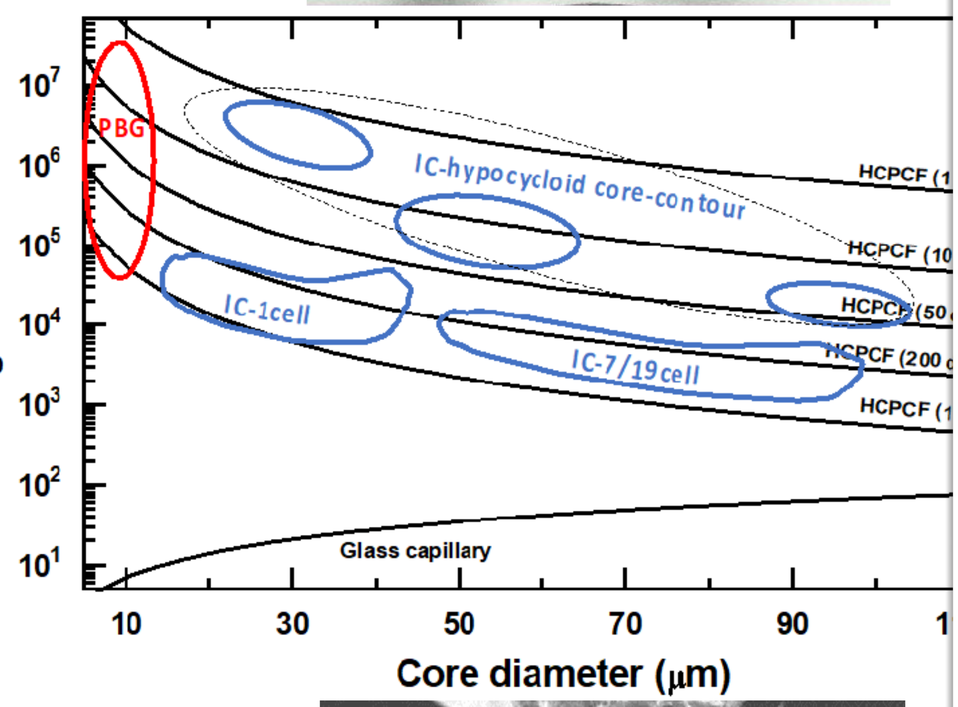
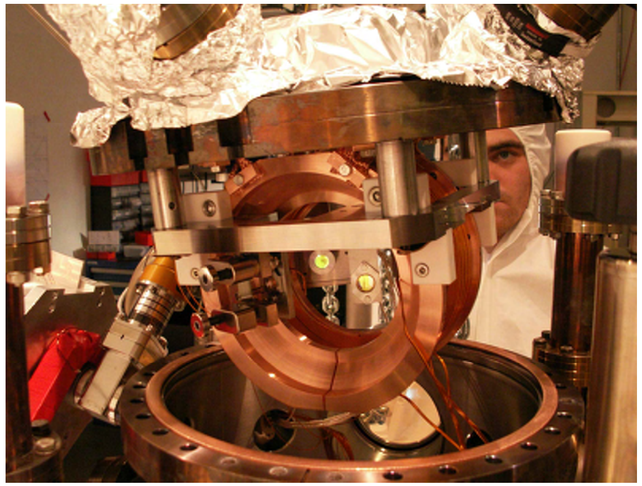
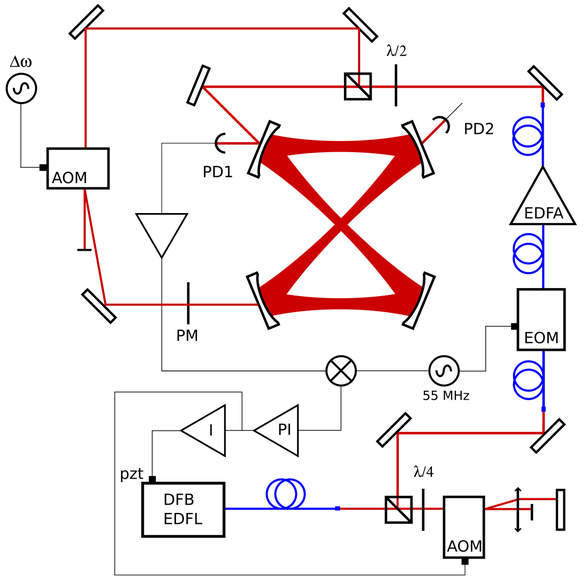
Inhibited Coupling



Up to Million Fold improvement in Atom-Light Coupling !!!

Alternative to Cavity Enhancement for Quantum Sensing





Standard Free Space Technology

Photonic Bandgap Fiber

GLO

Interaction	Environment	Range	Vacuum (mBar)	Compactness
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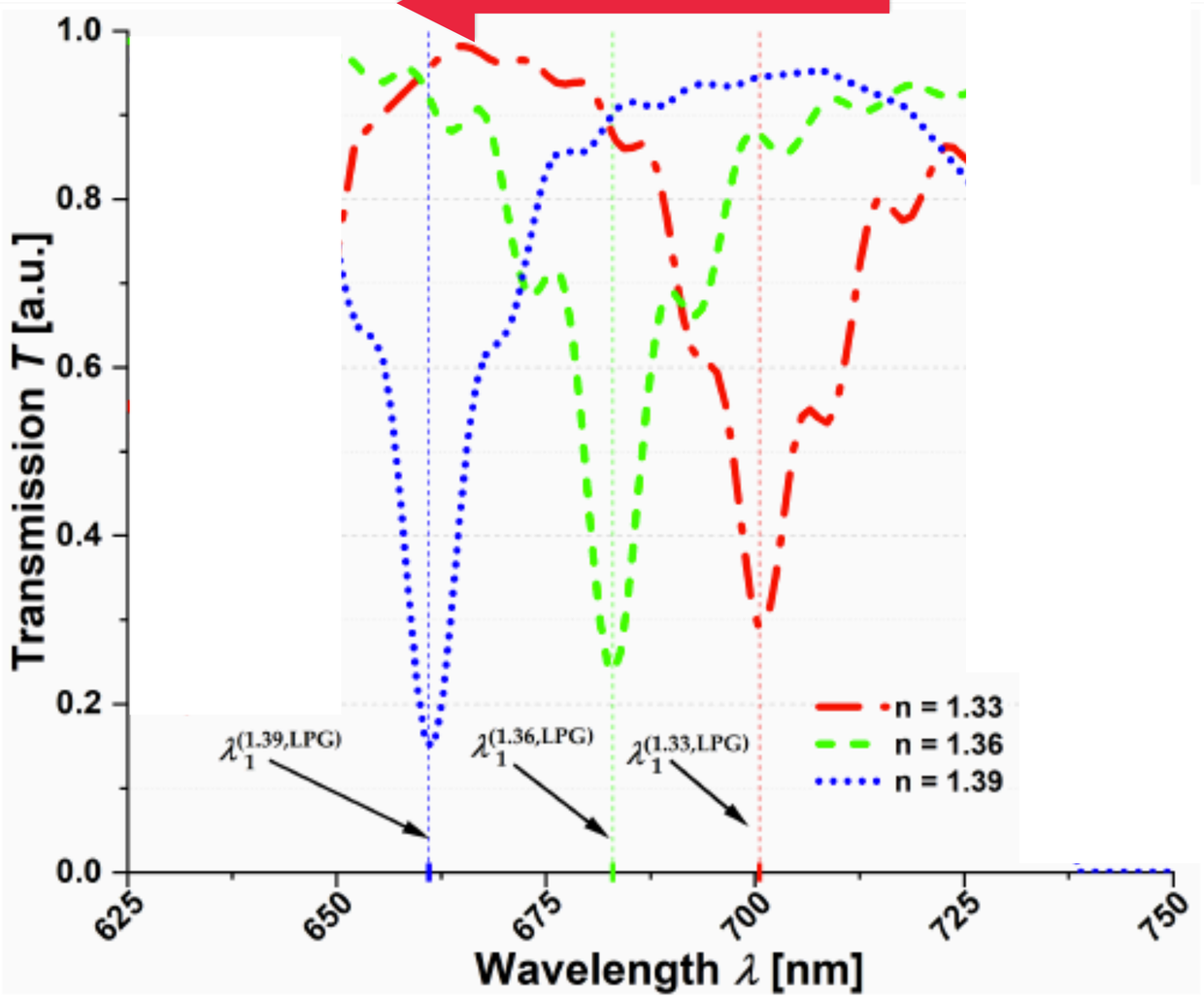
Quantum Enhanced Detection for Aqueous Solutions!!!

Liquid in core shifts Transmission Profile



High Light-Molecule Interaction in Liquid State:

- Urine Analysis
- Blood Analysis
- Aqueous Quantum Sensing

In Collaboration with:

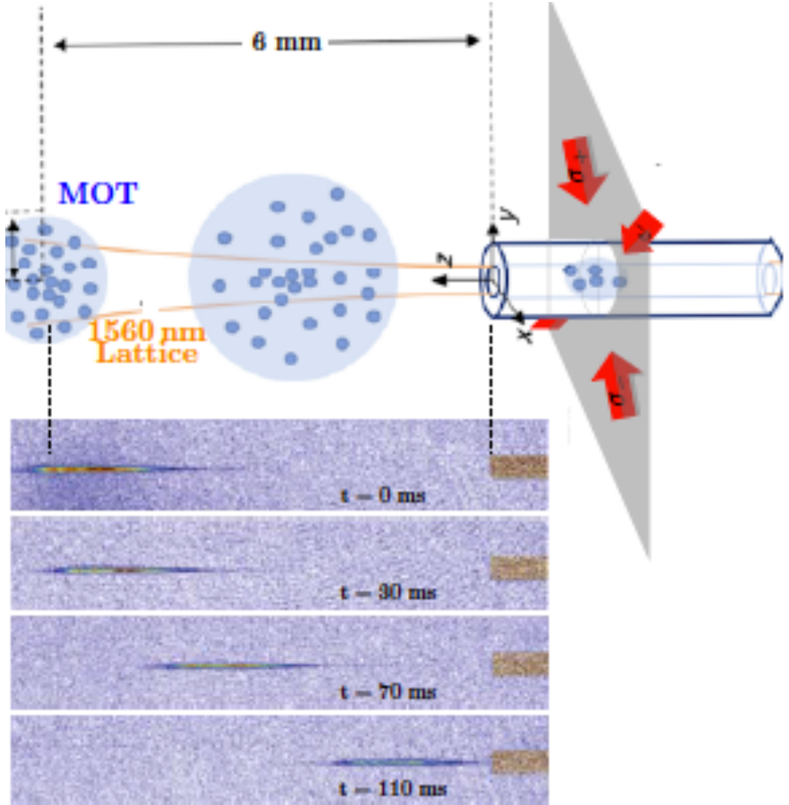
Space Tech

Menhir Photonics

universität innsbruck

Paving the way for Atom-Photonics

Warm, Cold, and Ultra-Cold Alkali Atom PMC



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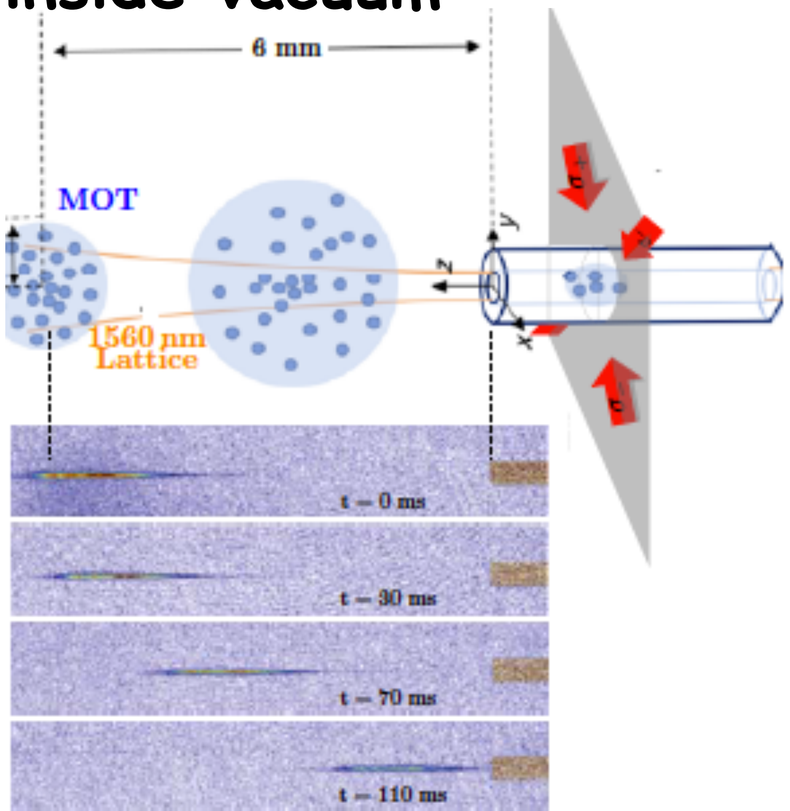
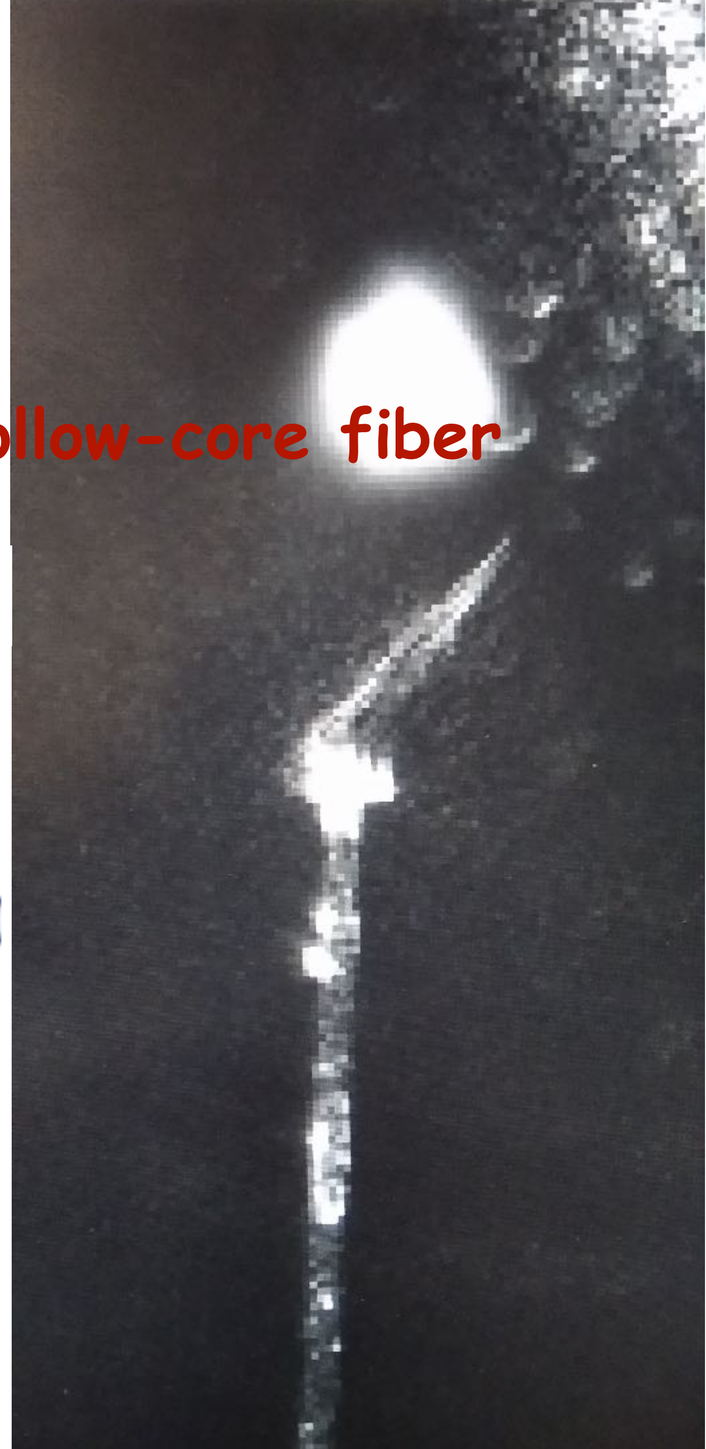
The Hollow-Core PCF & Photonic MicroCell™ company

Paving the way for Atom-Photonics

Warm, Cold, and Ultra-Cold Alkali Atom PMC

- a dense MOT of ^{87}Rb atoms near the entrance of a hollow-core fiber
  - 10^9 atoms/s at 10 microKelvin temperature
  - (planned) hermetic sealing inside vacuum





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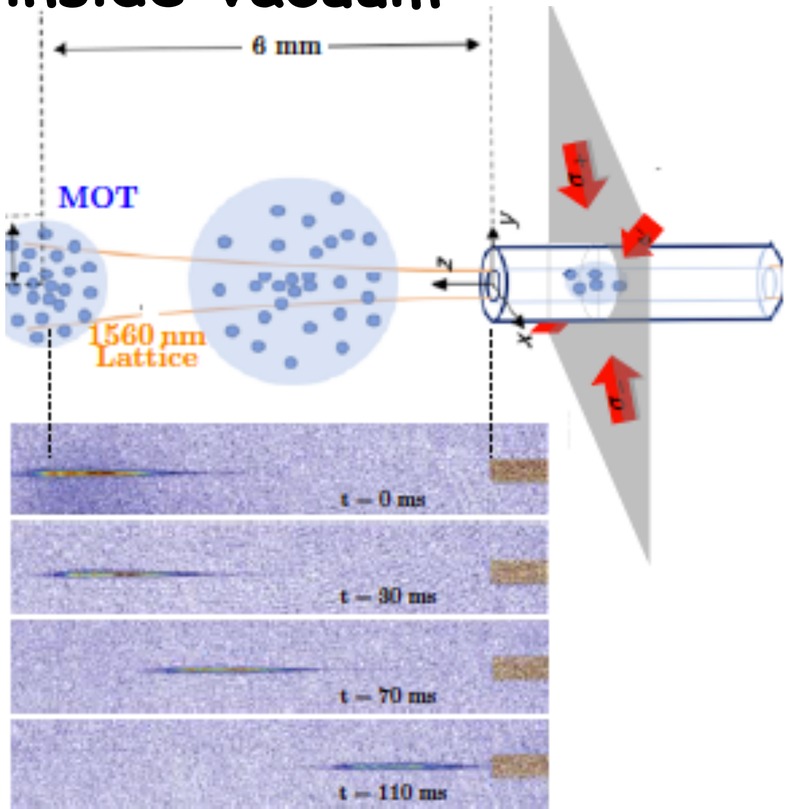
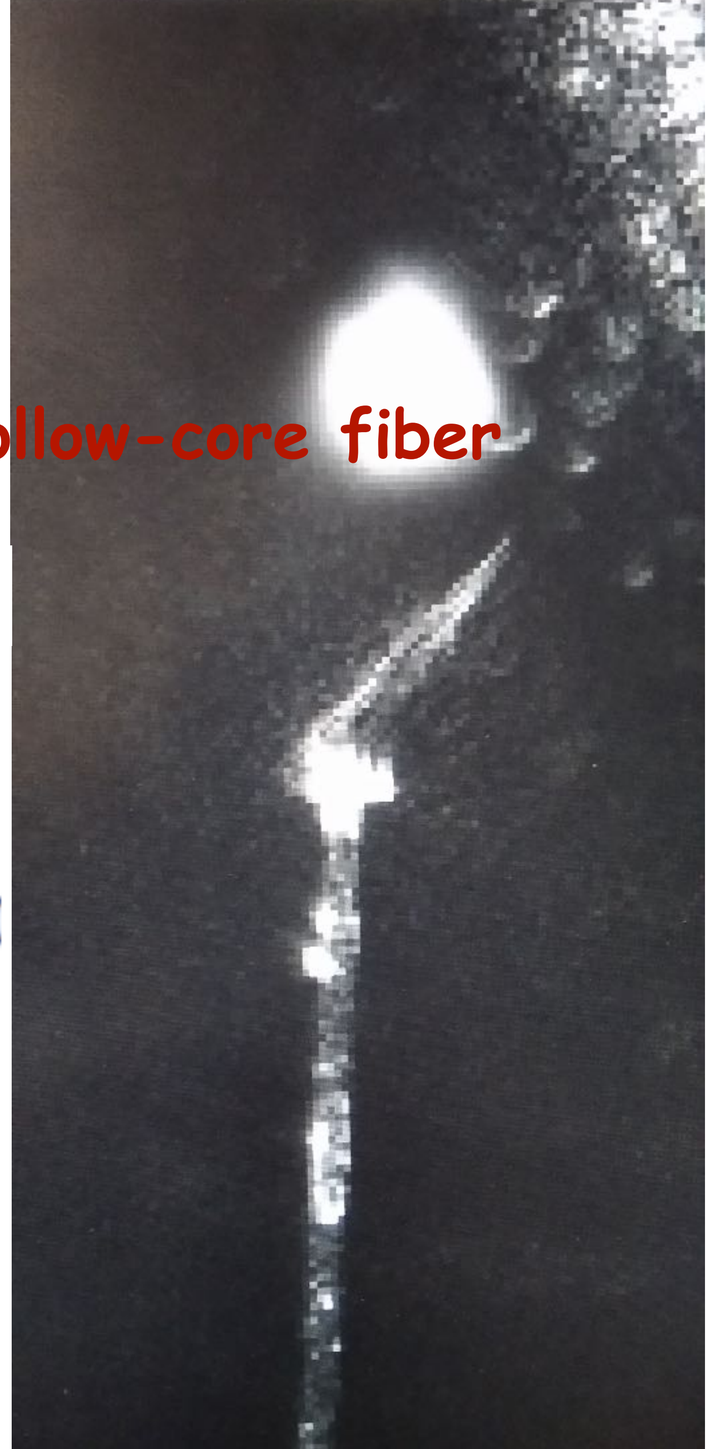
Quantum Memories (10 μs - 1 ms) + Transmission in One Platform





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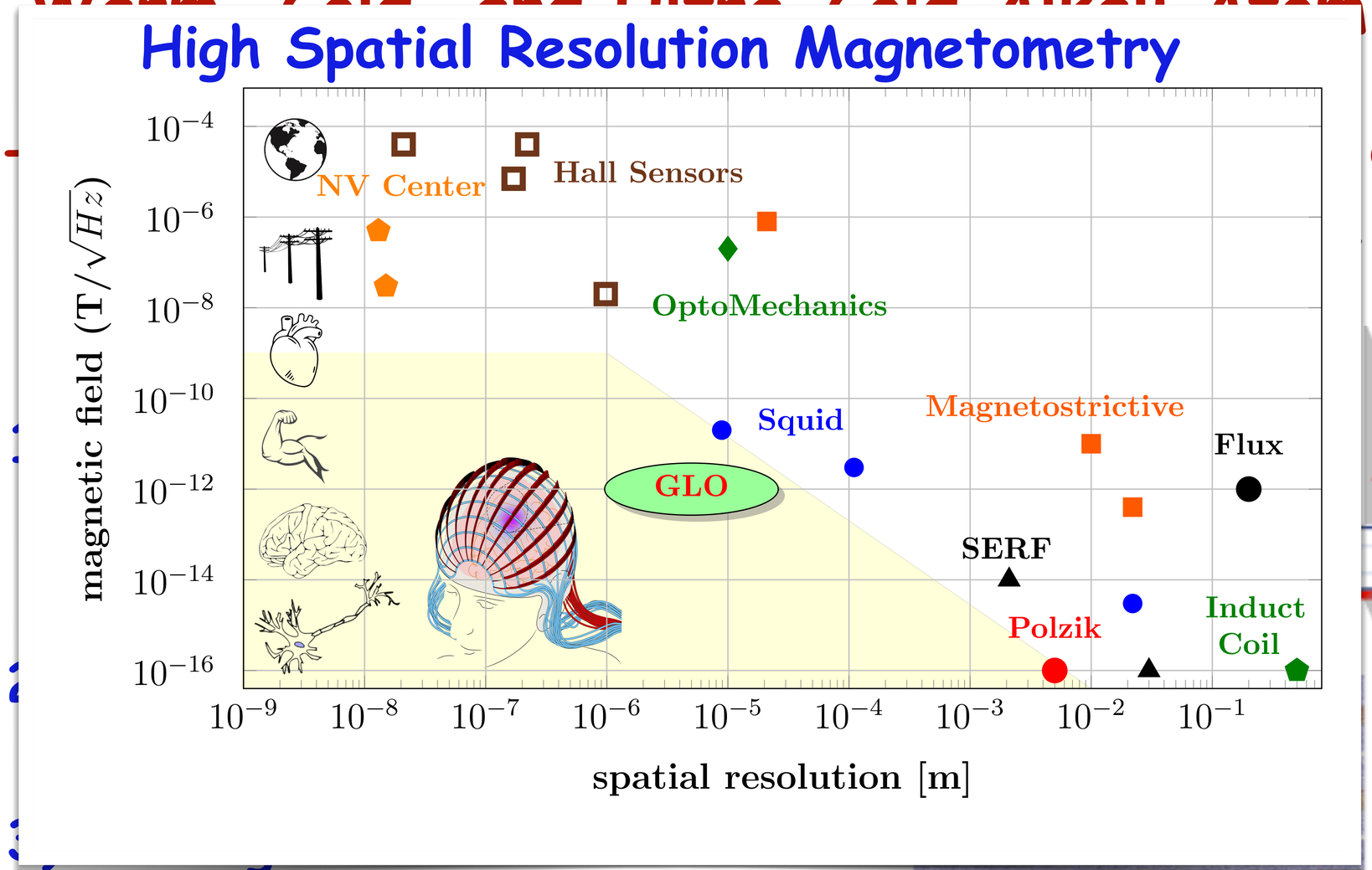
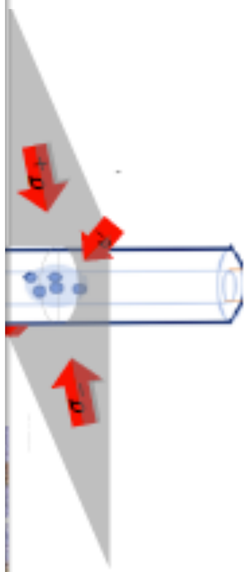
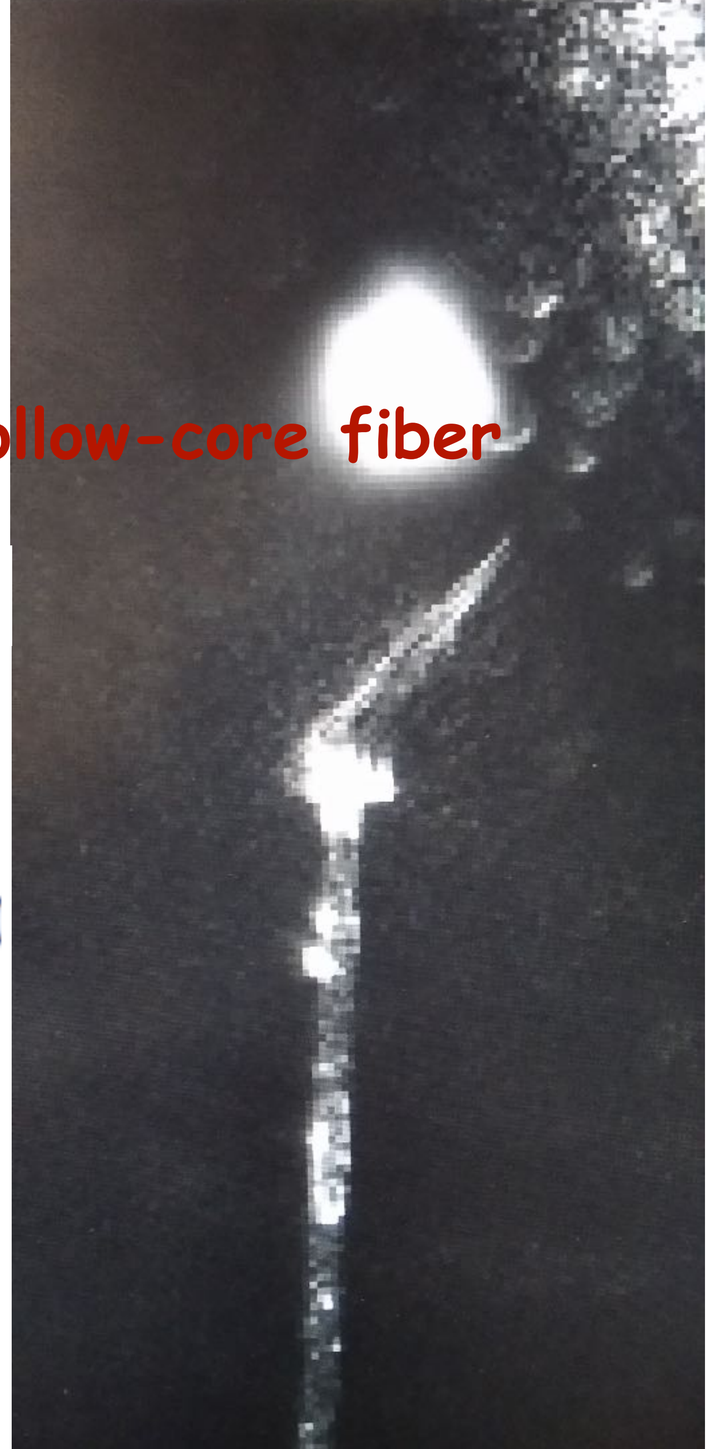
Paving the way for Atom-Photonics

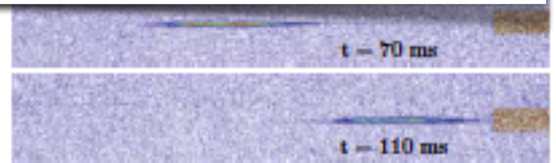
Warm, Cold, and Ultra Cold Alkali Atom PMC

of a hollow-core fiber









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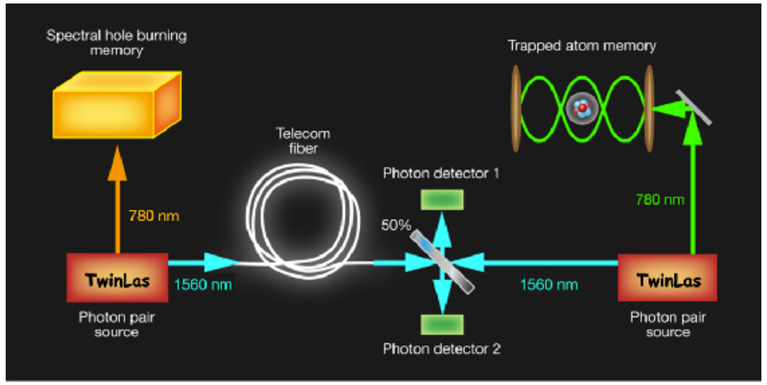
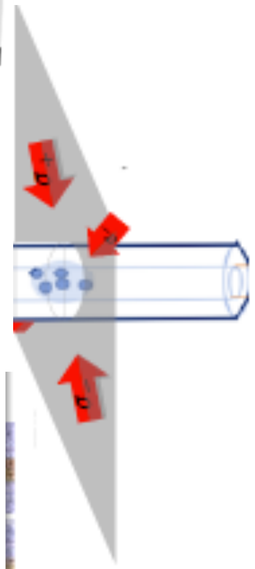
Paving the way for Atom-Photonics

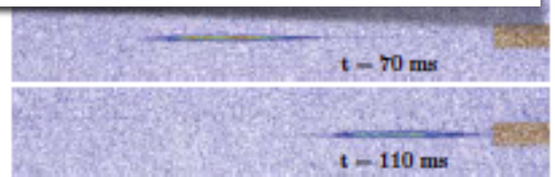
PMC

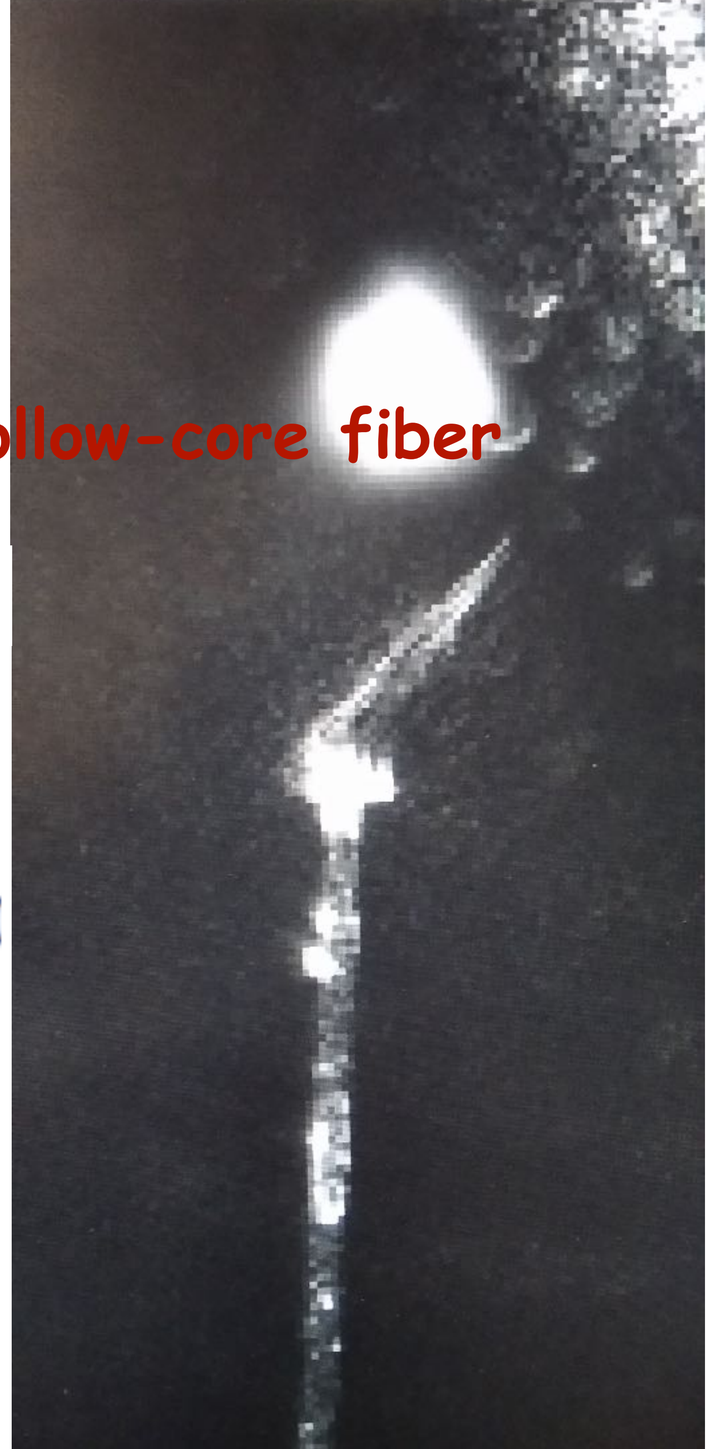
of a hollow-core fiber

All-Fibered 780 nm - 1560 nm Entangled Photon Source









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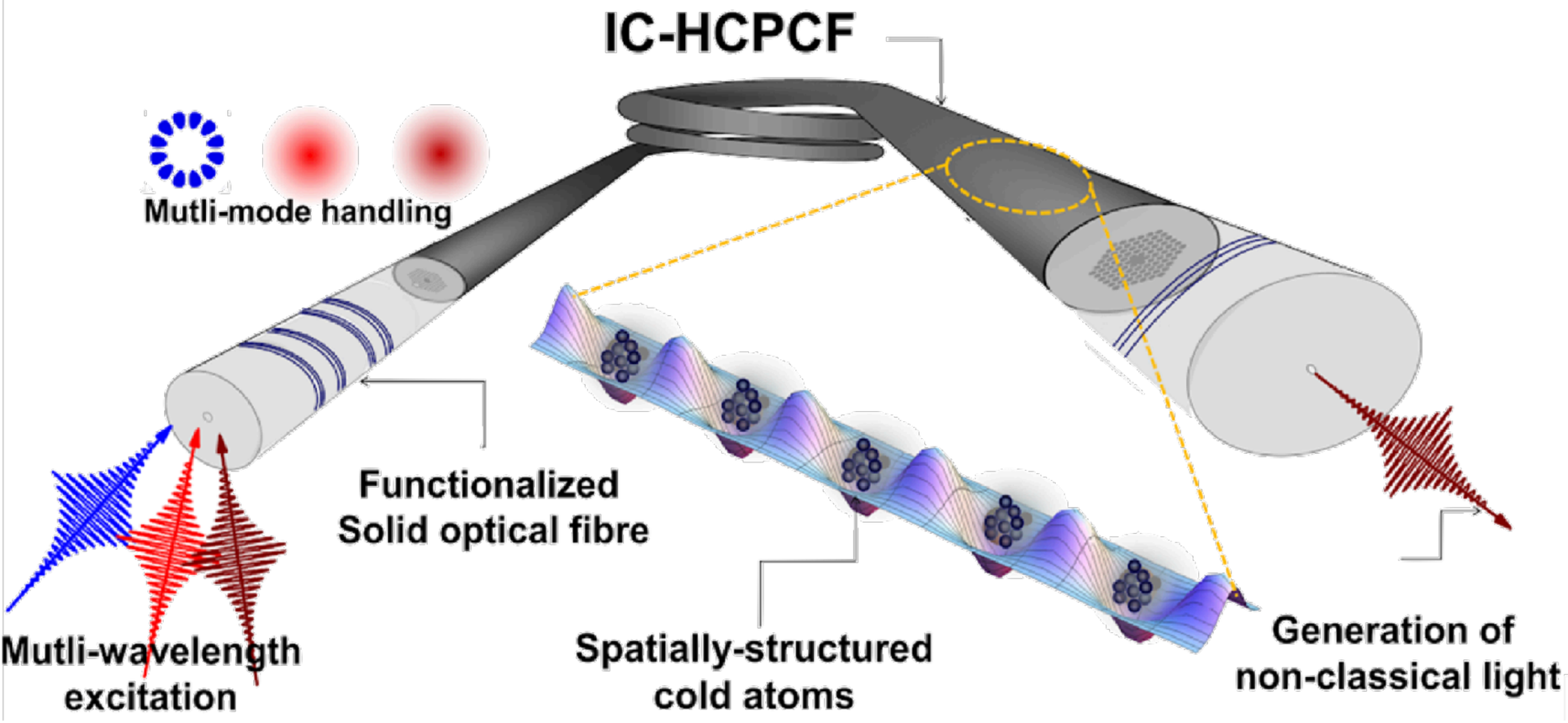
Paving the way for Cold-Atom Photonic Microcells



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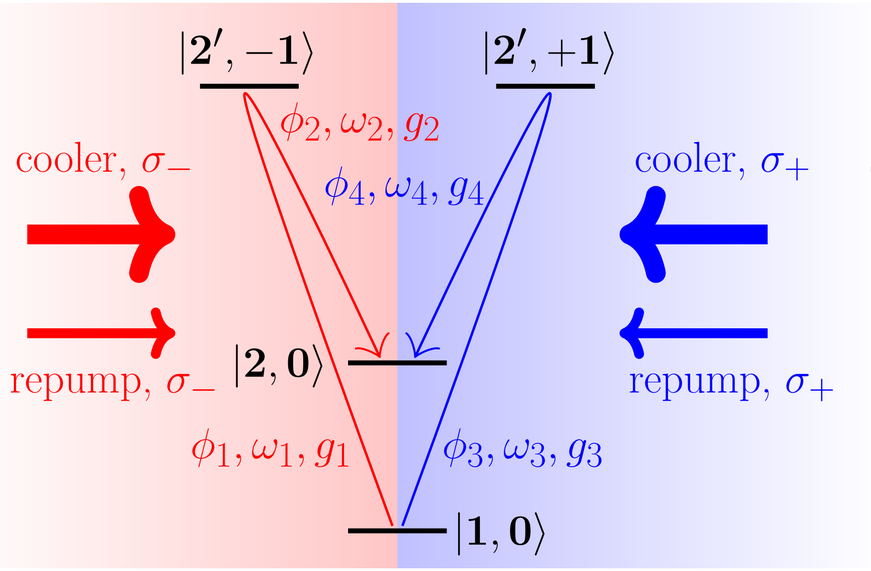
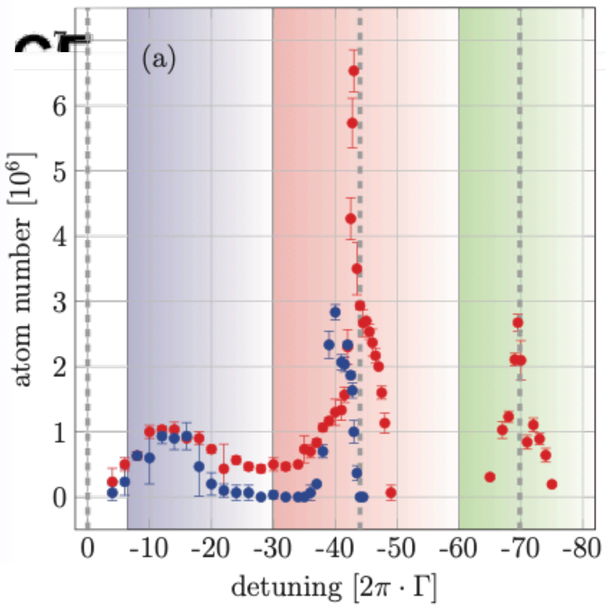
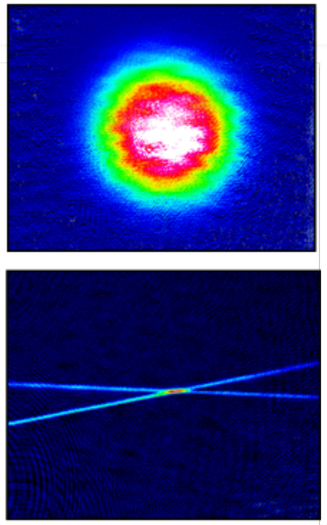
CRYST3

CRYST3 European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 964531

Paving the way for Cold-Atom Photonic Microcells







$$|Dark\ State\rangle = |\vec{p} - 2\hbar k, (2,0)\rangle + |\vec{p} + 2\hbar k, (1,0)\rangle$$

1) Phys. Rev. Research 2 , 013212 (2020) 2) Nature, *Sci Rep* 8, 1301 (2018) 3) Phys. Rev. Research 4, L022058 – 13 June 2022

Cooling Inside the Fiber

Cooling in Fiber to 1 μK allows 20 ms of free evolution for quantum sensing

GLOphotonics
The Hollow-Core PCF & Photonic MicroCell™ company

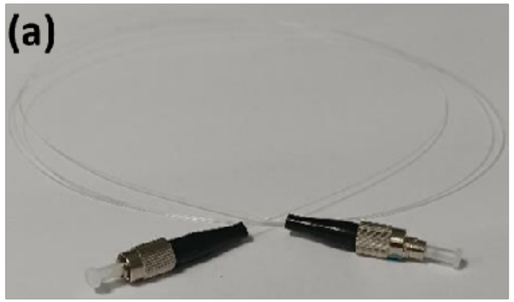
CRYST3

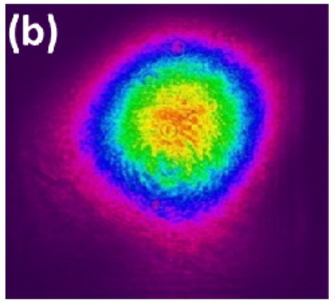
CRYST3 European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 964531

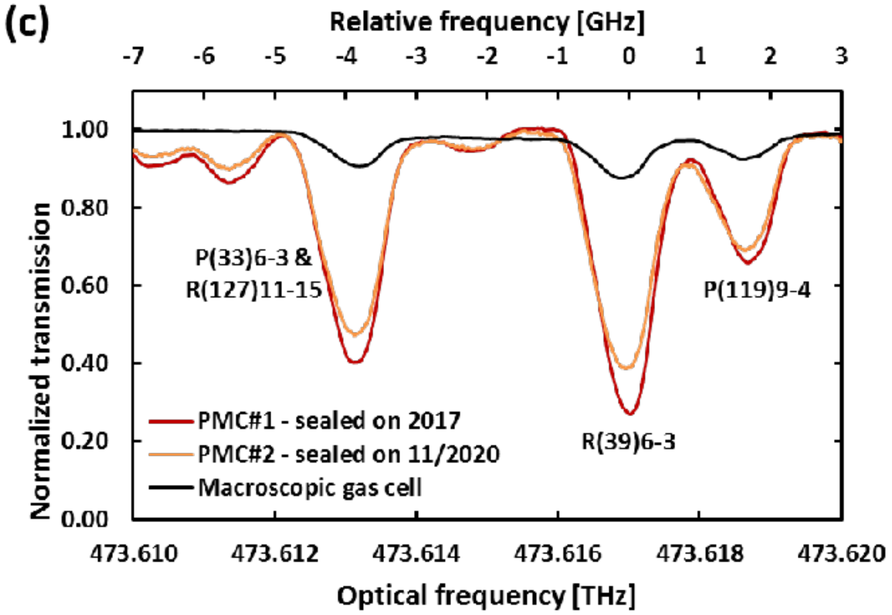
The Photonic Microcell: A proven enabler for science and technology

FREQUENCY REFERENCES:

I2 & C2H2 PMC

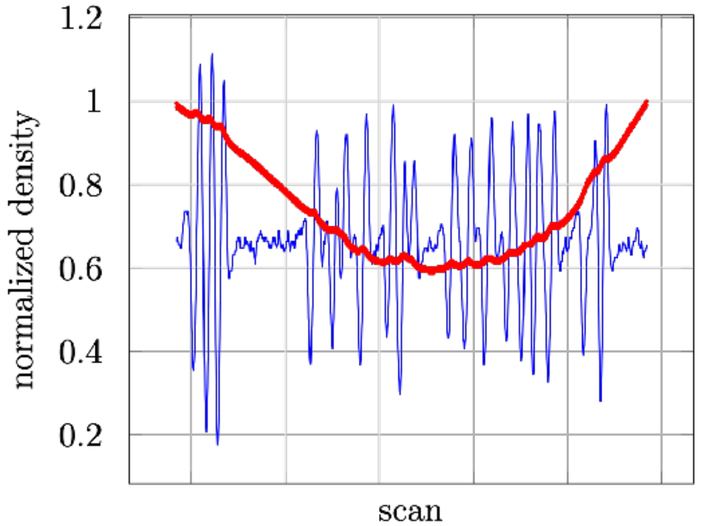


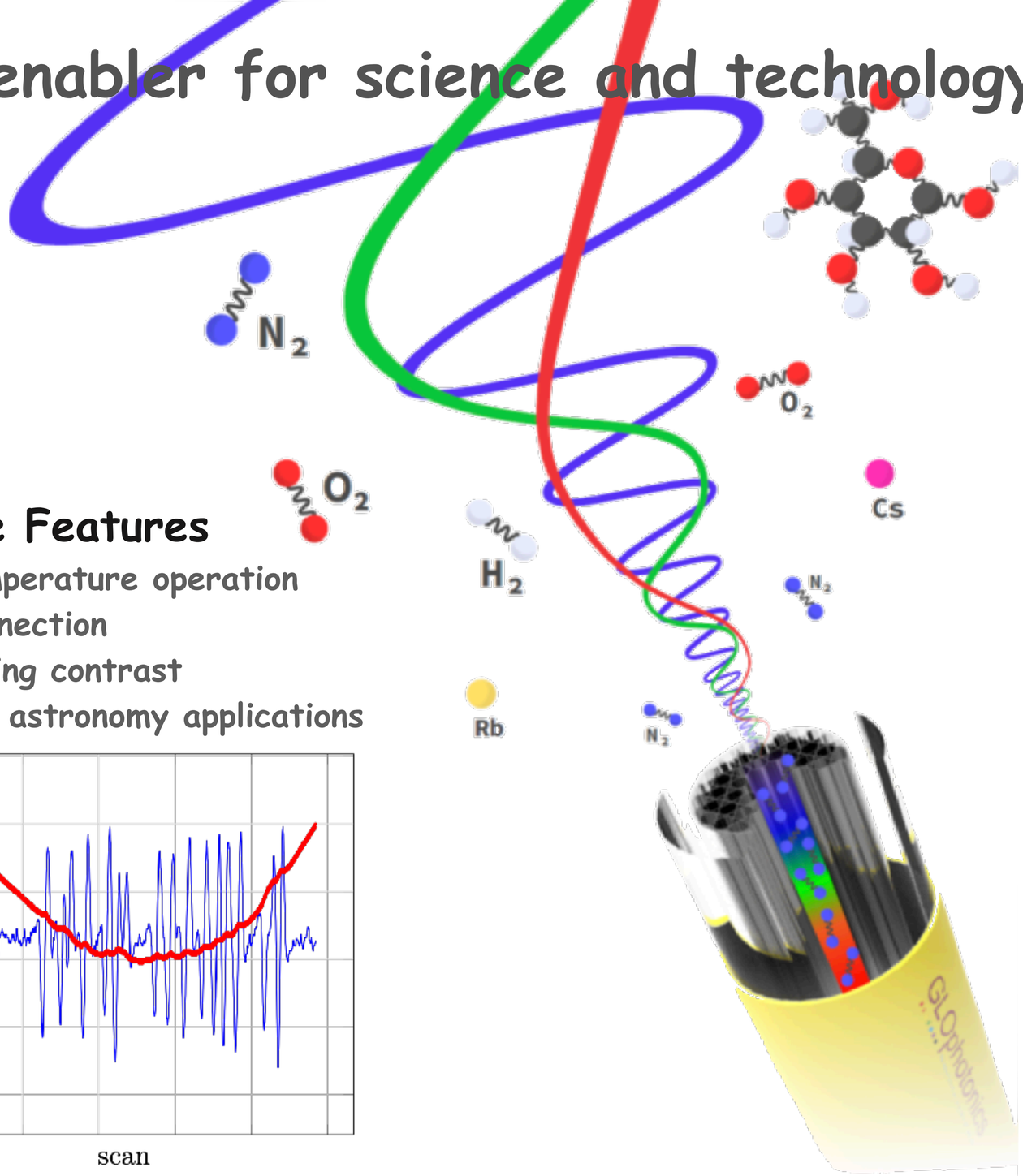




Unique Features

- Room temperature operation
- Fiber connection
- Outstanding contrast
- Ideal for astronomy applications





The Photonic Microcell: A proven enabler for science and technology

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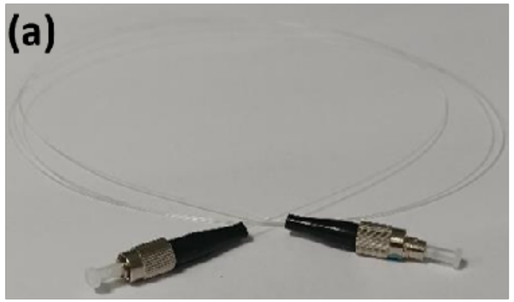
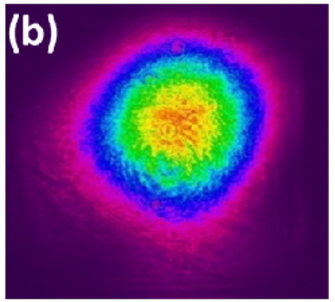
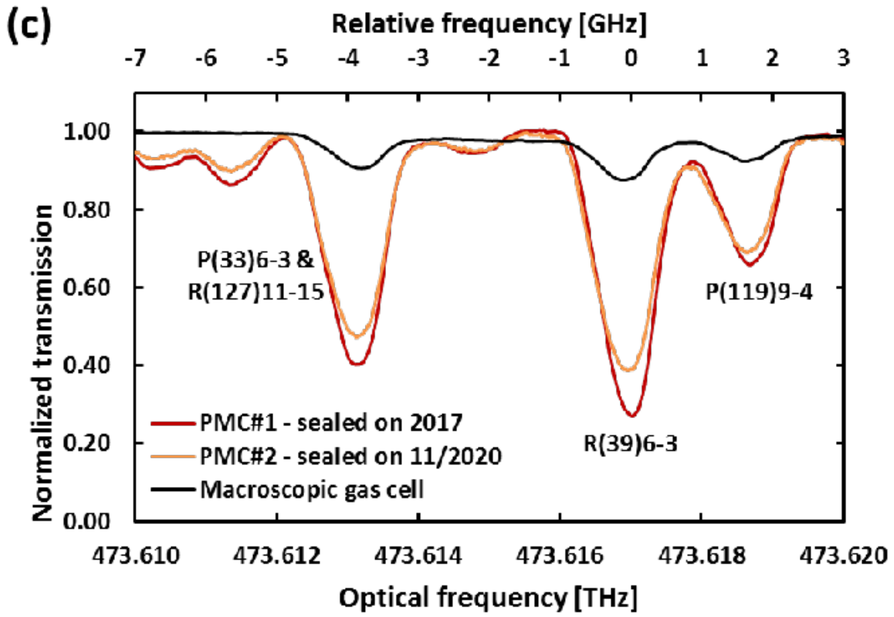




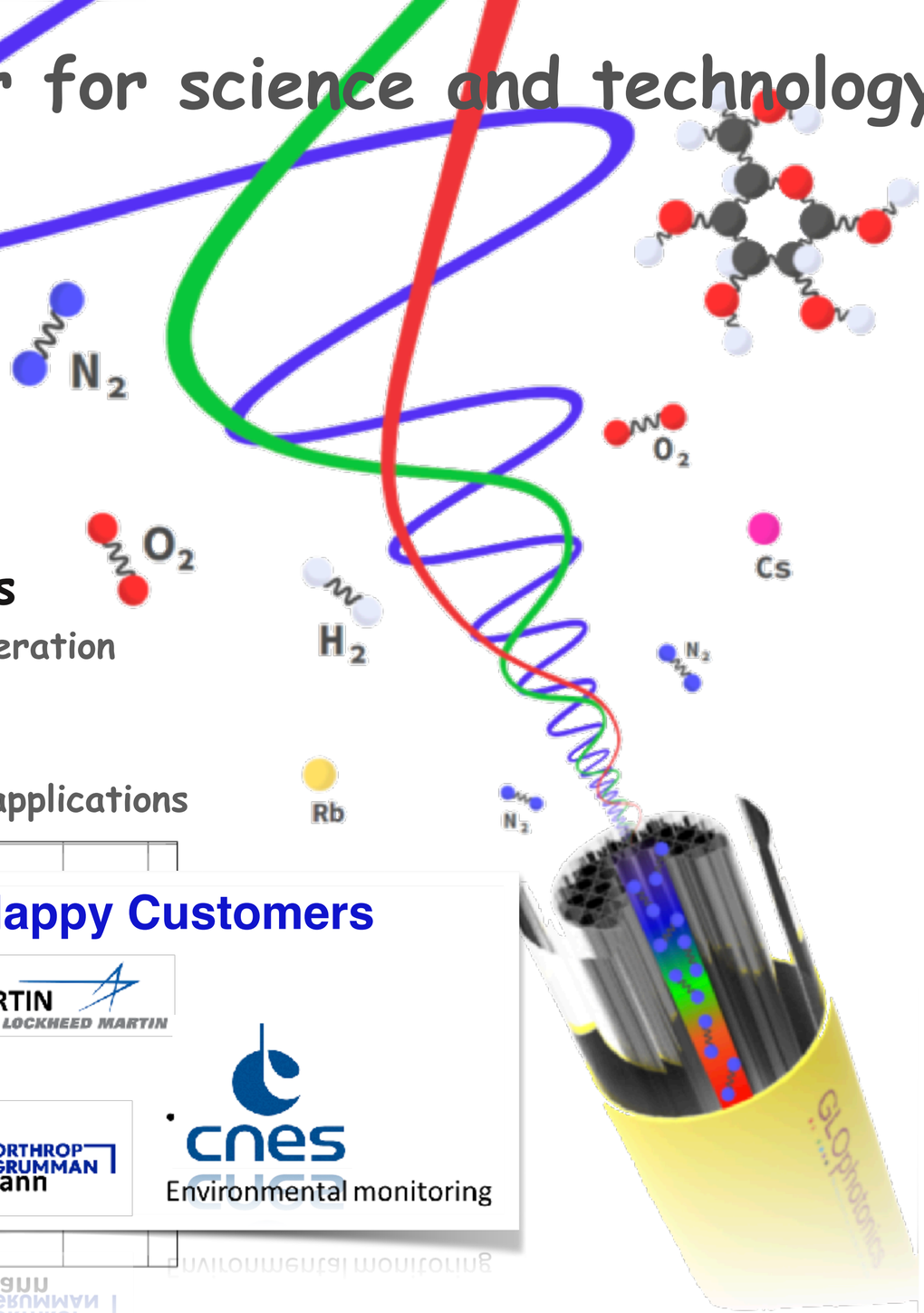


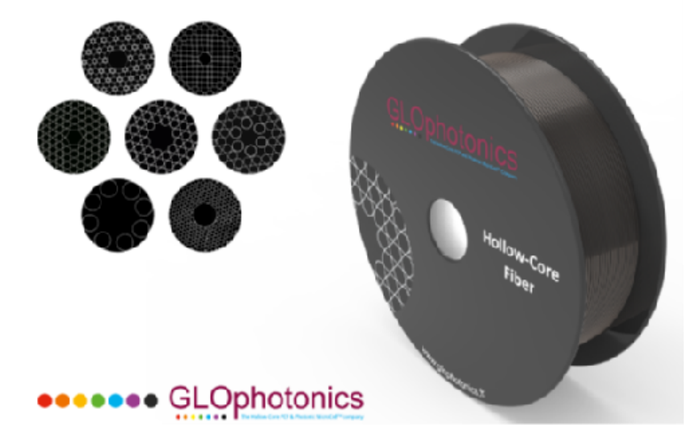
Unique Features

- Room temperature operation
- Fiber connection
- Outstanding contrast
- Ideal for astronomy applications

Happy Customers

- NASA
  Environnemental monitoring
- LOCHEED MARTIN
  Defence
- ESA
  Quantum metrology
- Northrop Grumann
  Space technology
- cnes
  Environmental monitoring





GLOphotonics

The company

Merci Beacoup

A French start-up based in Limoges. Incubation in Bath (**2008**). Transfer to and re-incubation in Limoges (**July 2011**). Trading activities in **2013**

~20 employees. 80% in R&D, 12 PhD+

150 m² clean room (ISO-07)

2 drawing fiber towers

Stratetic partenership with XLIM / GPPMM

Development & supply of photonic components, modules and/or systems based on a proprietary Technology*.

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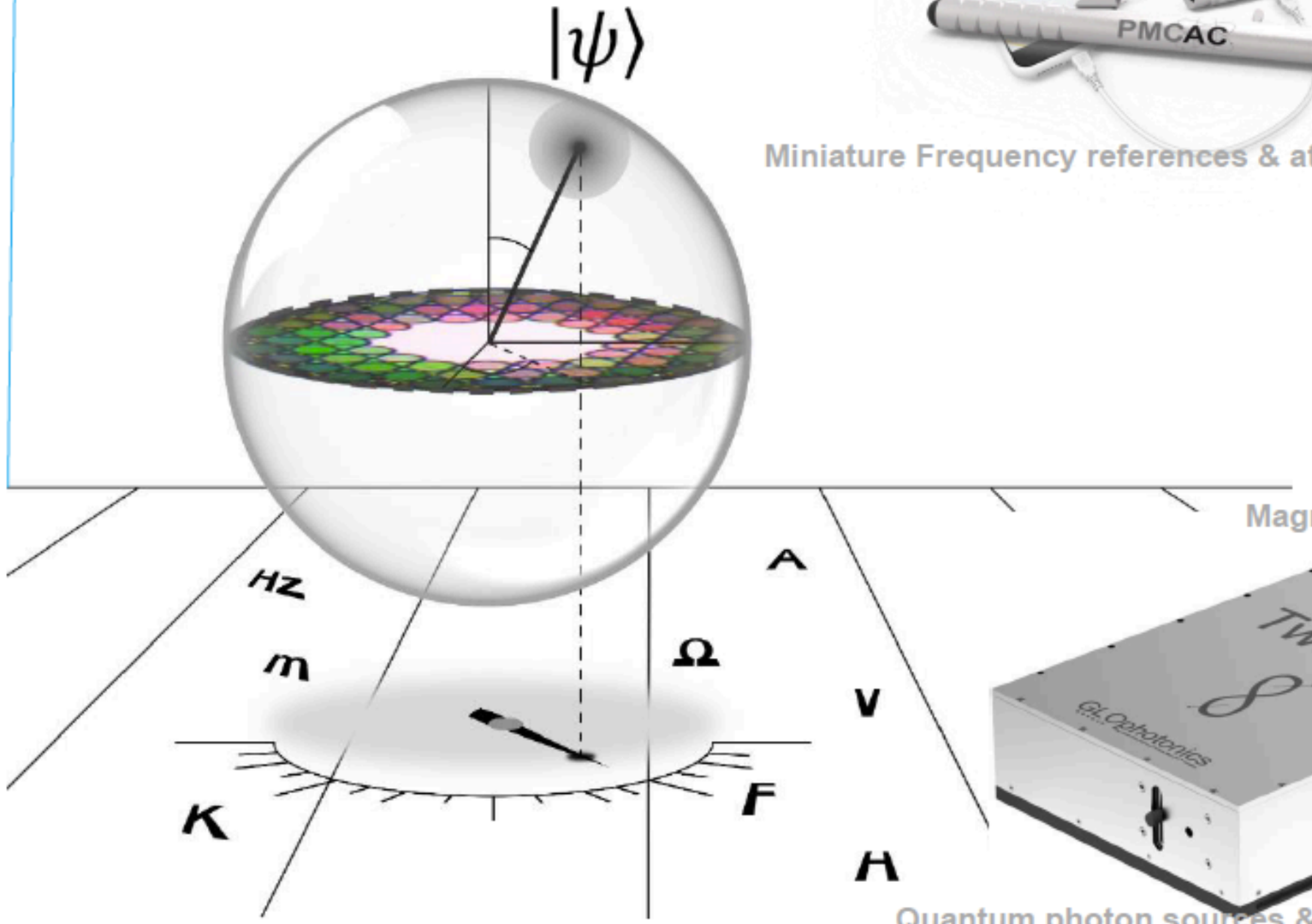
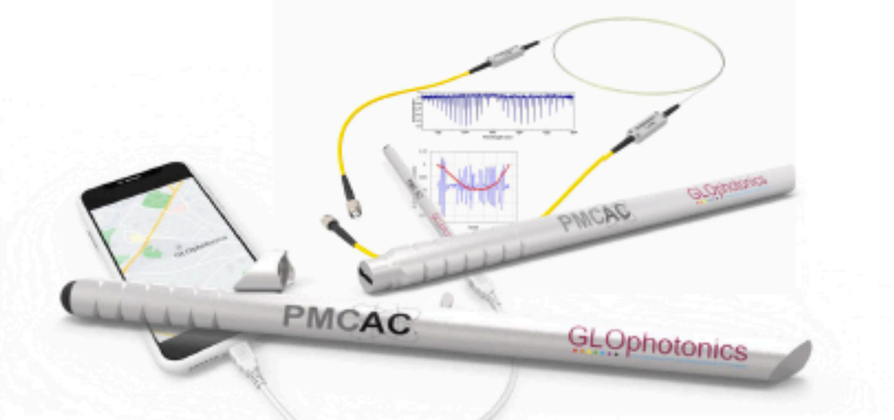
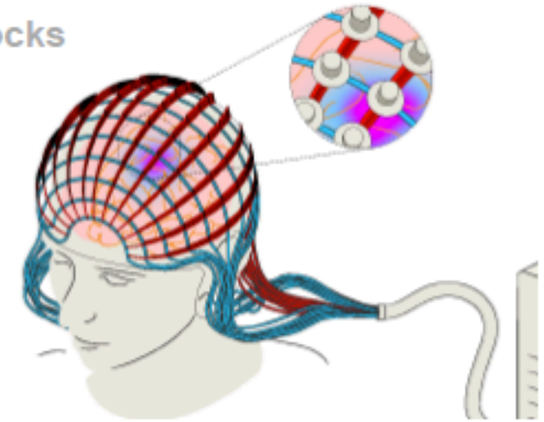
Quantum Technology Unit





Miniature Frequency references & atomic clocks

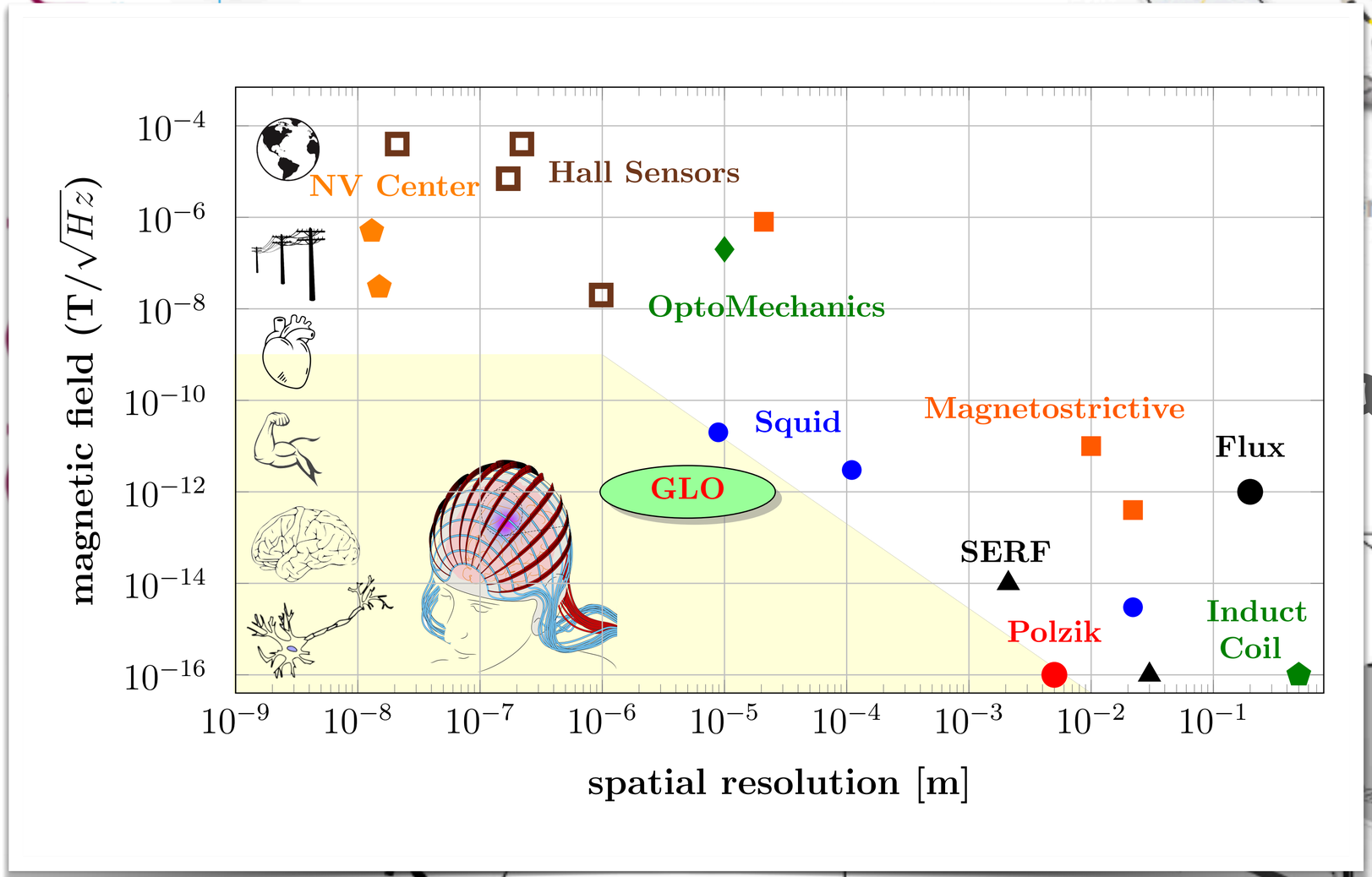
CES INNOVATION AWARDS 2023 HONOREE

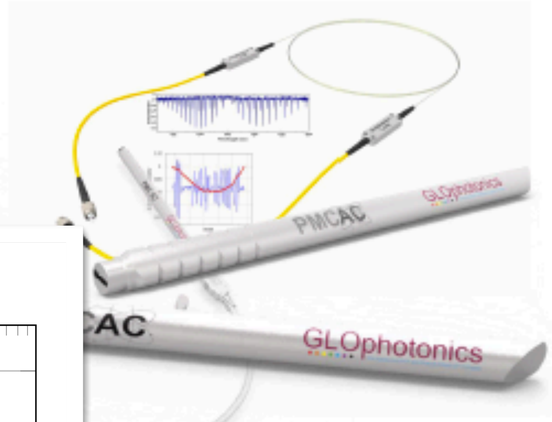


Magnetometry & brain imaging system

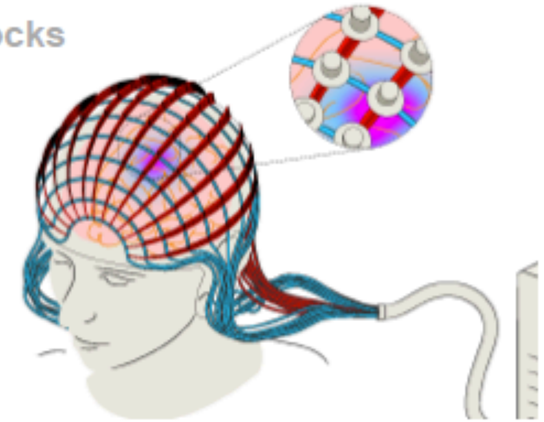
Quantum photon sources & memories

Quantum Technology Unit





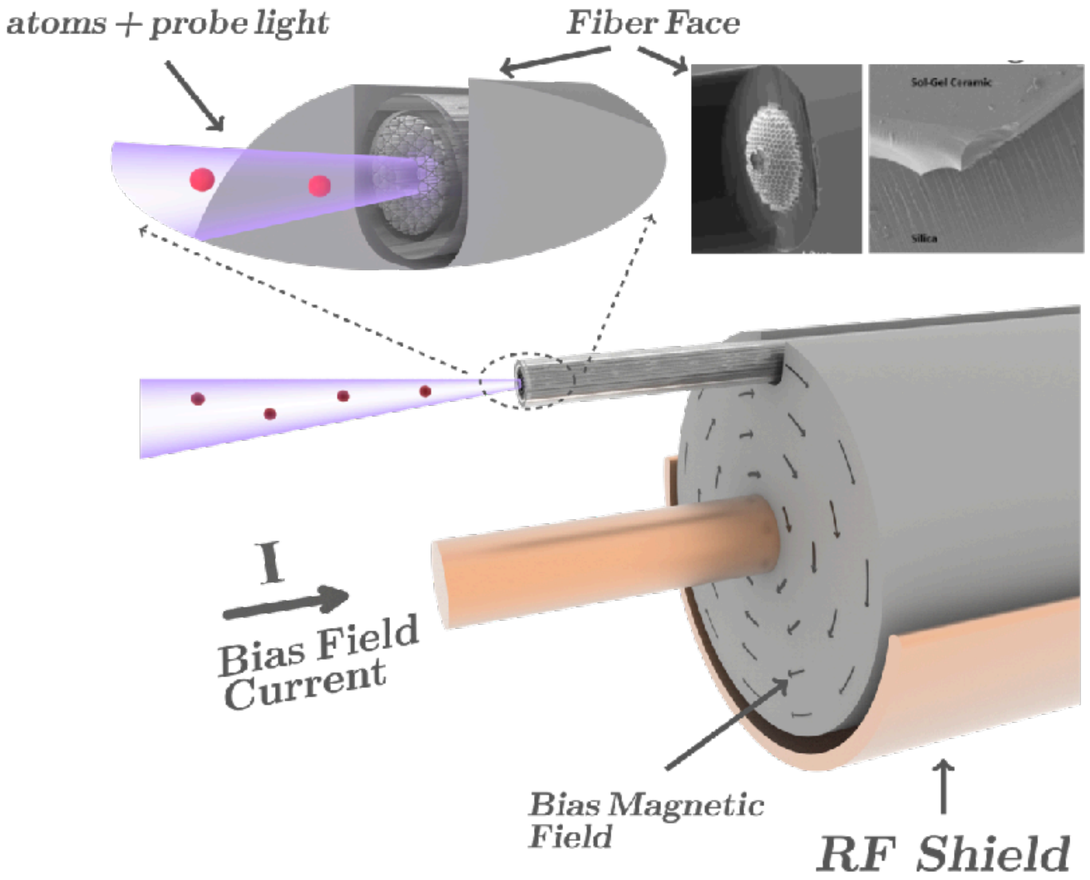
nces & atomic clocks



Magnetometry & brain imaging system

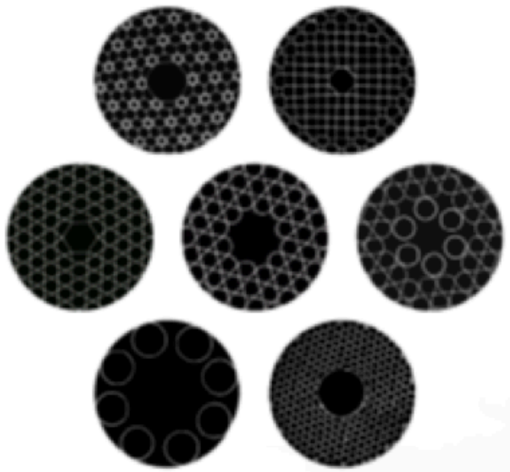
Quantum photon sources & memories

A Novel Quantum Sensing Architecture



Novel Quantum Sensing Architecture spanning decades of spatial scale:

1) integrated optics,
2) integrated microwave delivery system,
3) integrated detection



1. F. Benabid, L. Vincetti, F. Giovanardi, "ELECTROMAGNETIC WAVEGUIDE," Patent 20220244452, July 30, 2020.
2. F. Benabid, "Hollow-core photonic crystal fibre," Patent 8306379, Nov. 6, 2012.
3. F. Benabid, "Optical assembly of a hollow core fibre gas cell spliced to fibre ends and methods of its production," Patent 8079763, Dec. 20, 2011.

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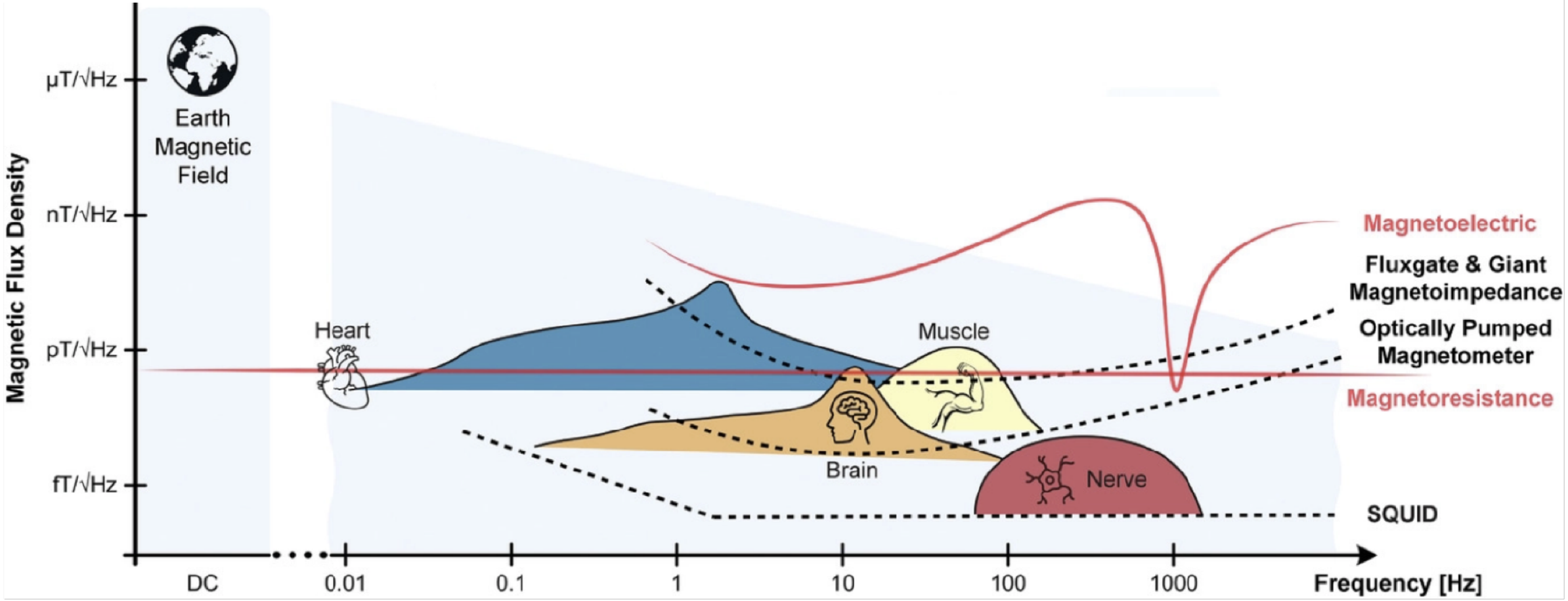
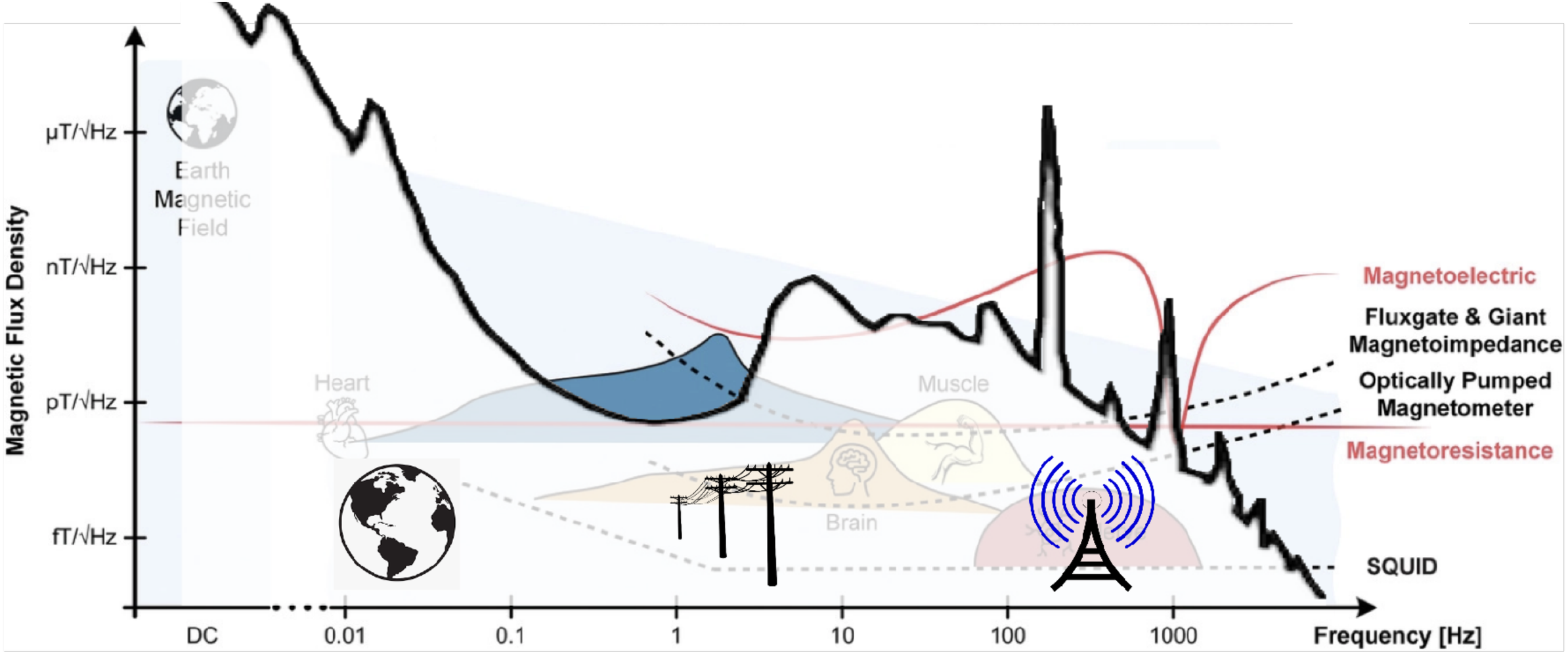
Our approach: use Quantum Sensors to measure the imperceptibly small magnetic response of biological tissues

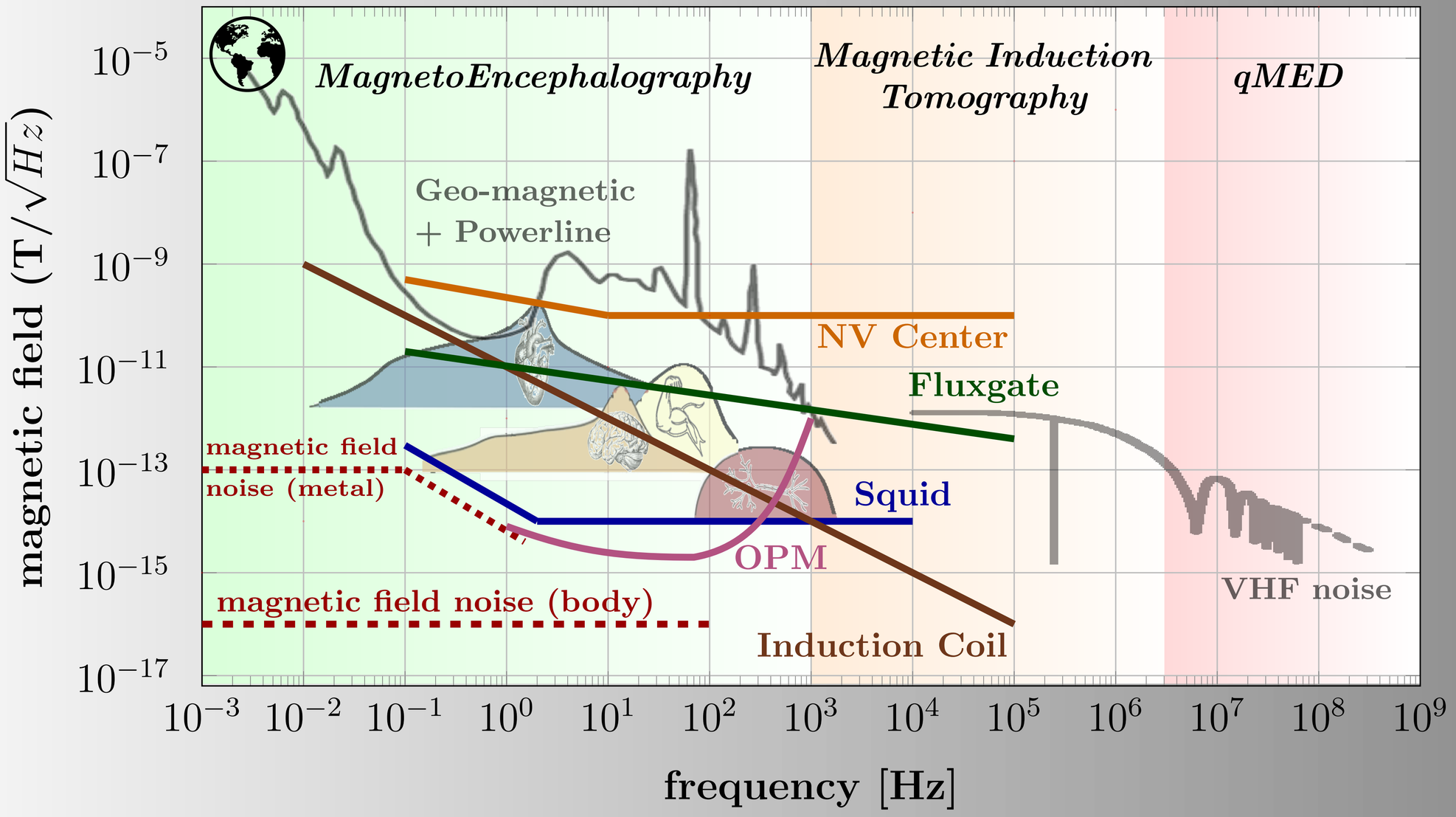


Recent advances are revealing the bio-magnetic nature of the human body

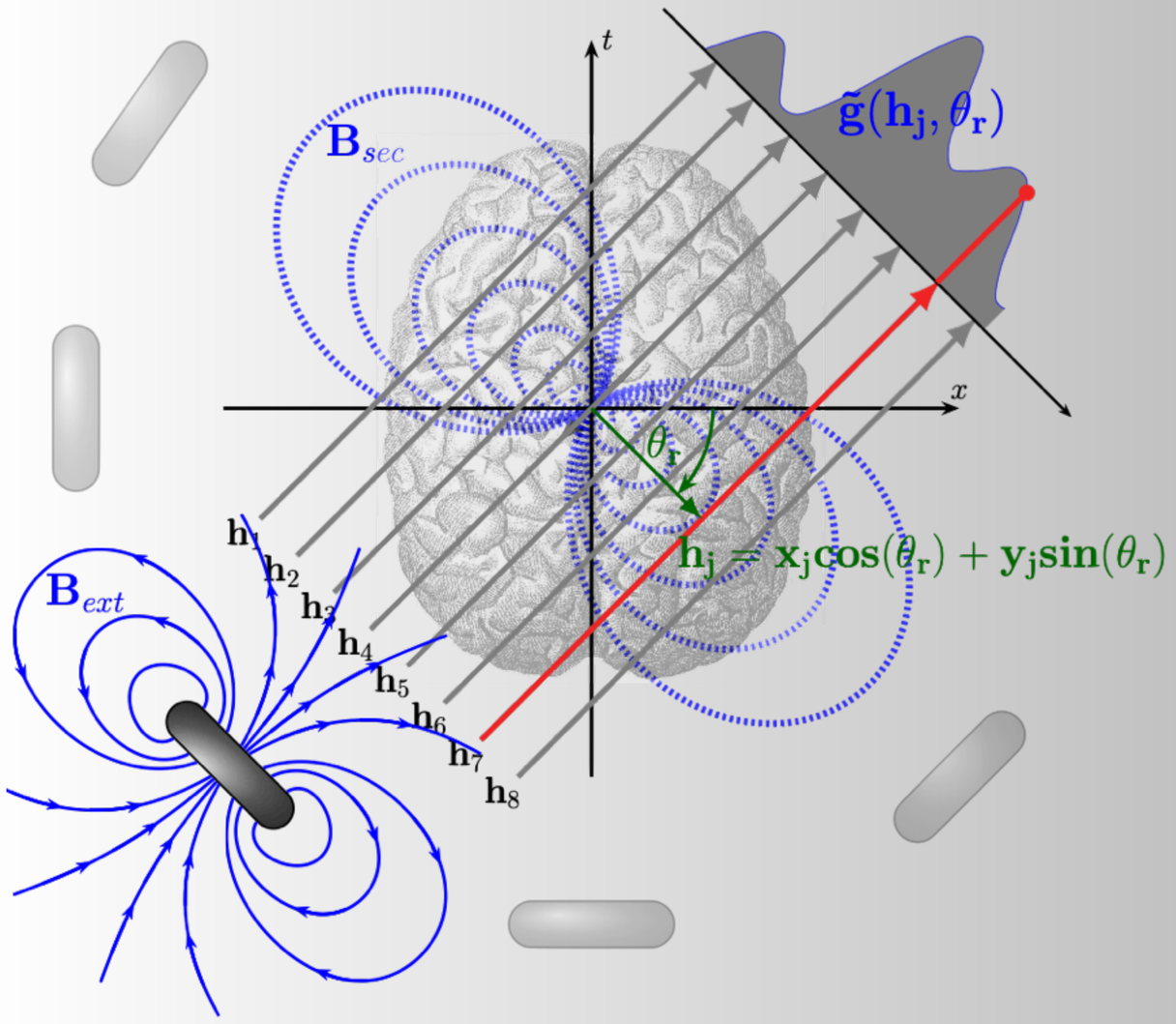
However the signals are very weak …

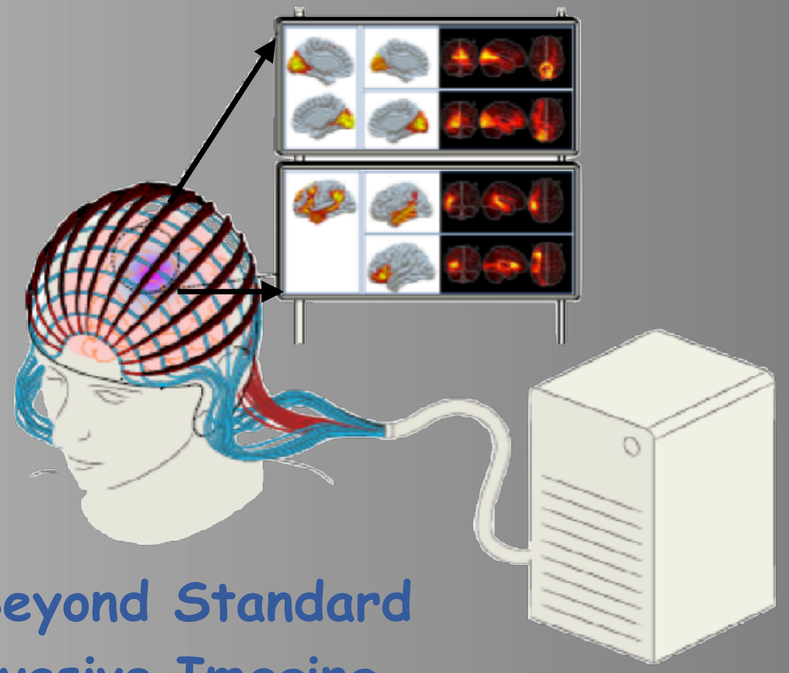


9 order of magnitude reduction in noise!!!!!



Navigating the Body with Magnetic Fields

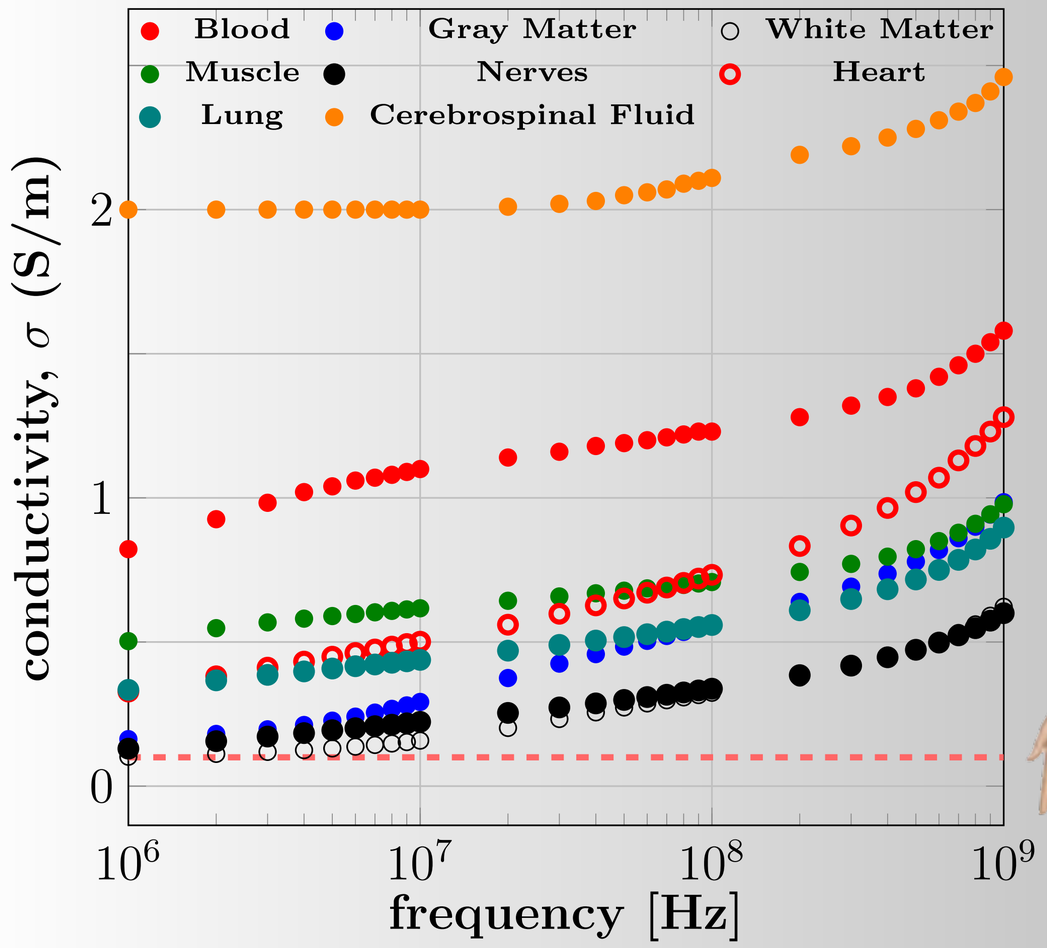


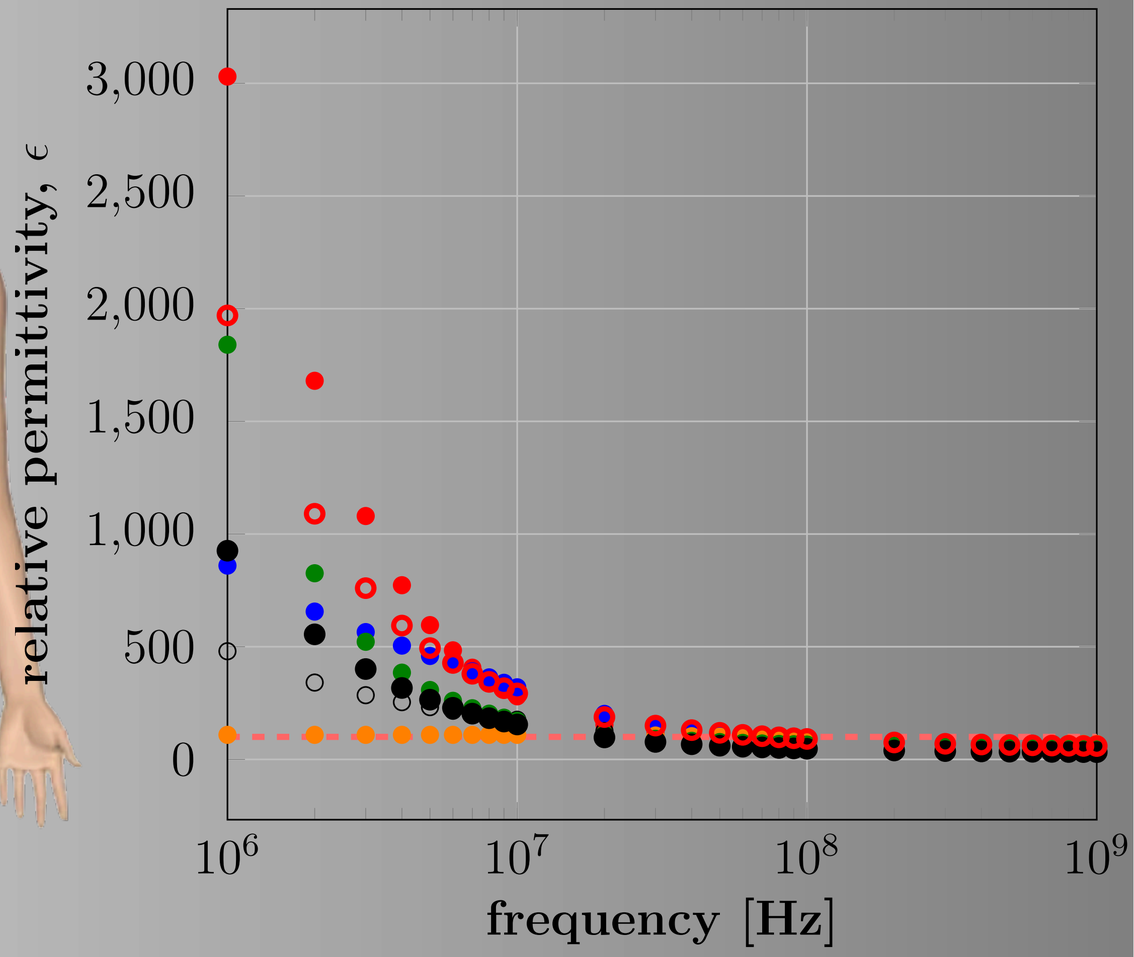


Going Beyond Standard
Non-Invasive Imaging

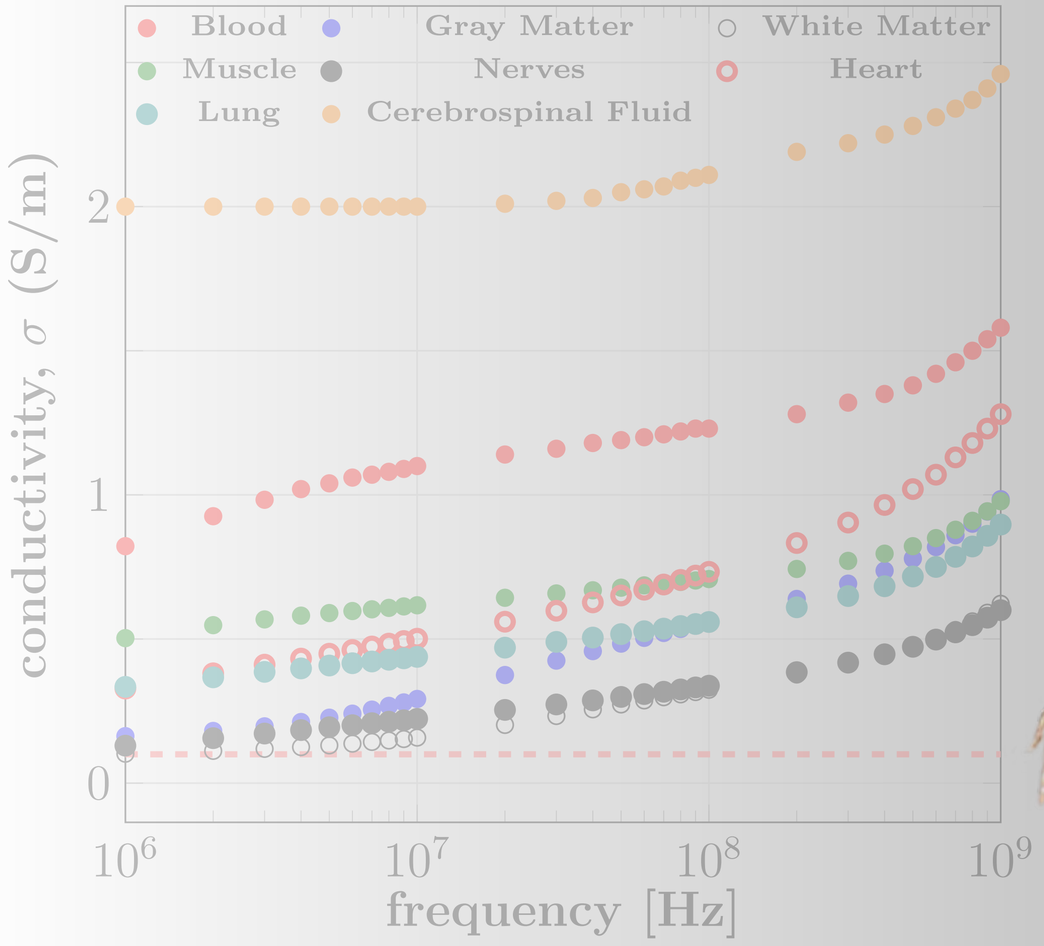
Our Quantum Sensors can probe vital Dielectric Properties of biological tissues: opening the door to a revolutionary new non-invasive, tissue-specific, structural imaging!!!

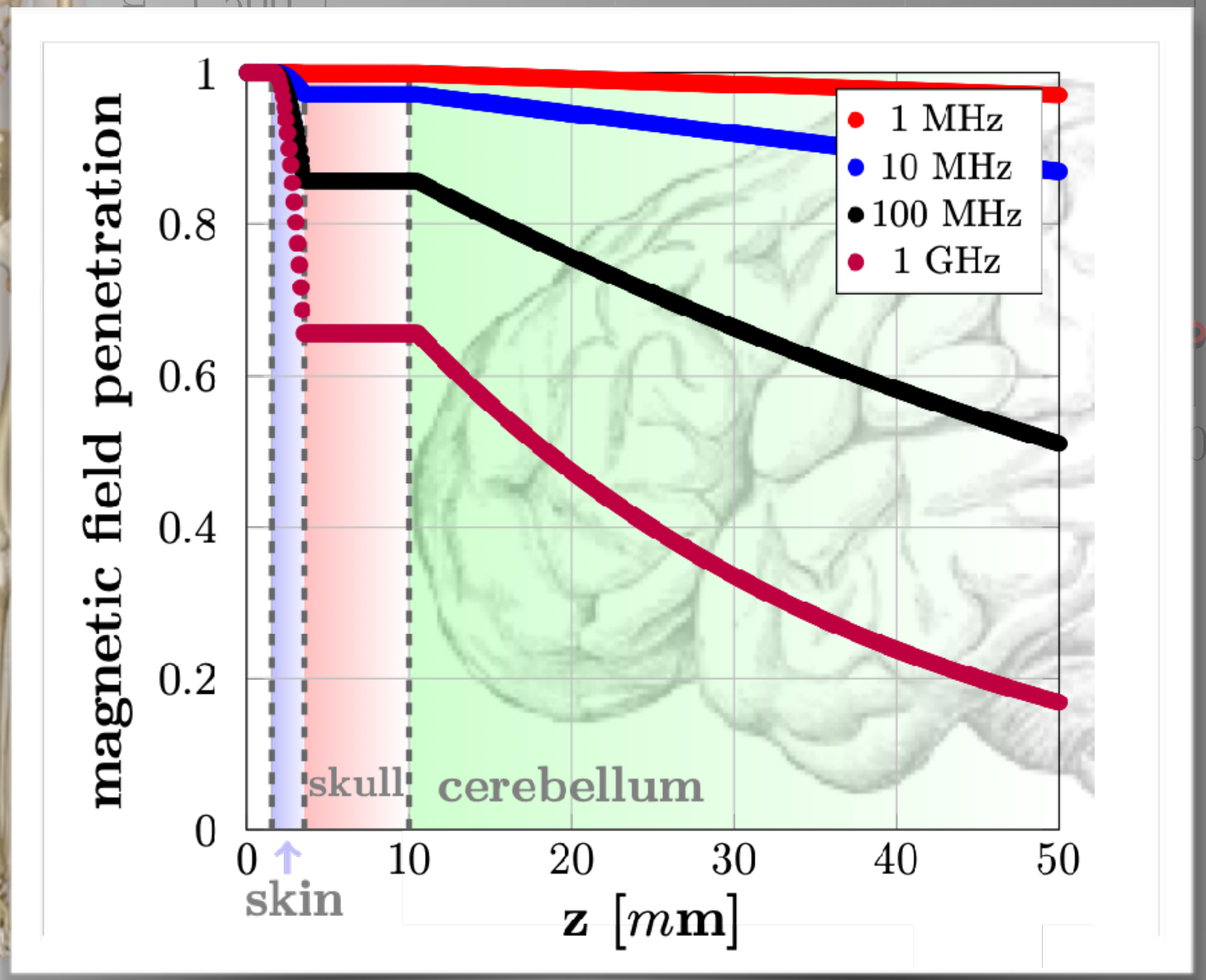
$$\mathbf{B}_{\mathbf{sec}}(\omega) = \{Q\omega\mu_0[\omega\varepsilon_0(\varepsilon_r - 1) - i\sigma] + P(\mu_r - 1)\}\mathbf{B}_{\mathbf{ext}}(\omega)$$





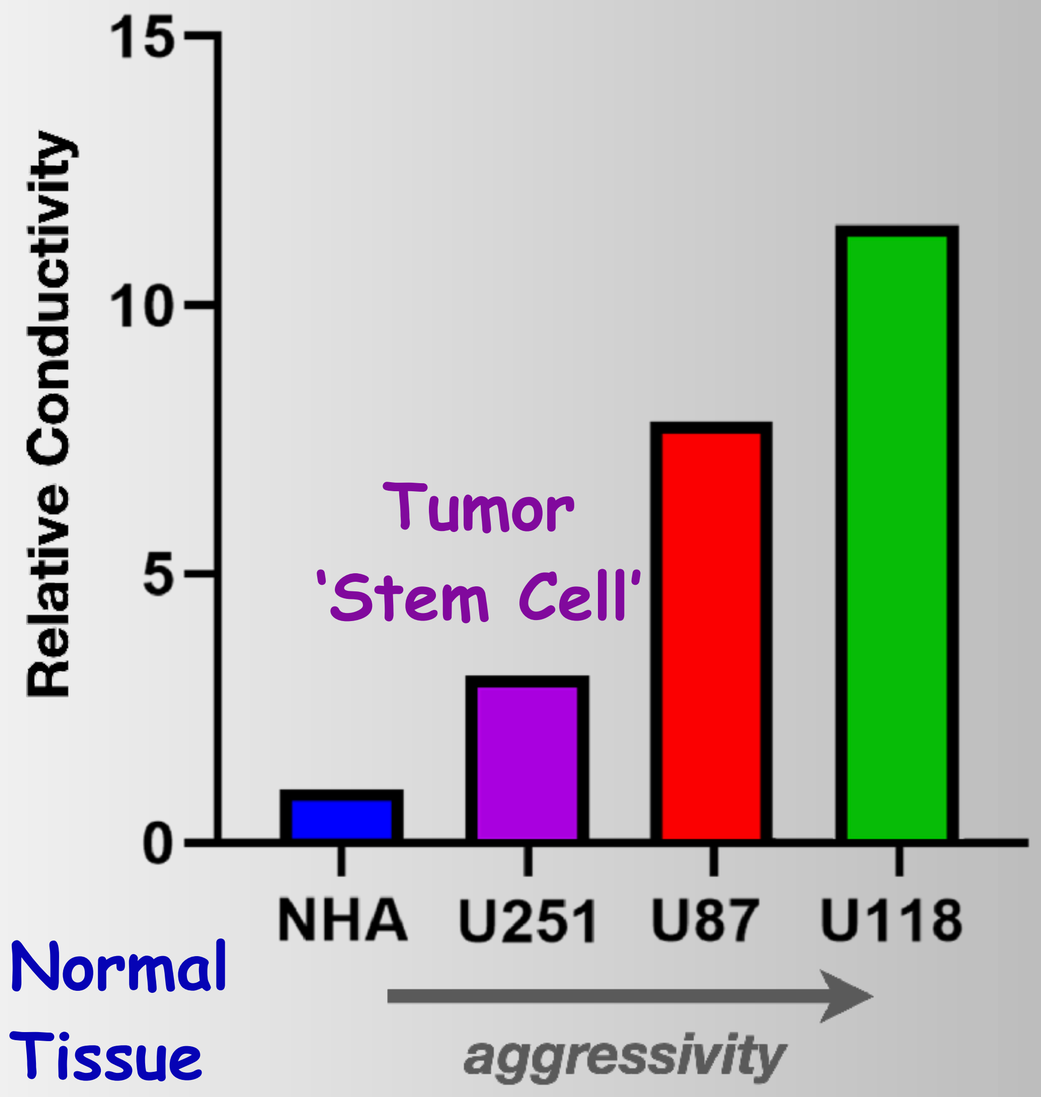
Measuring Conductivity allows Mapping Tissues across the Human body !!!





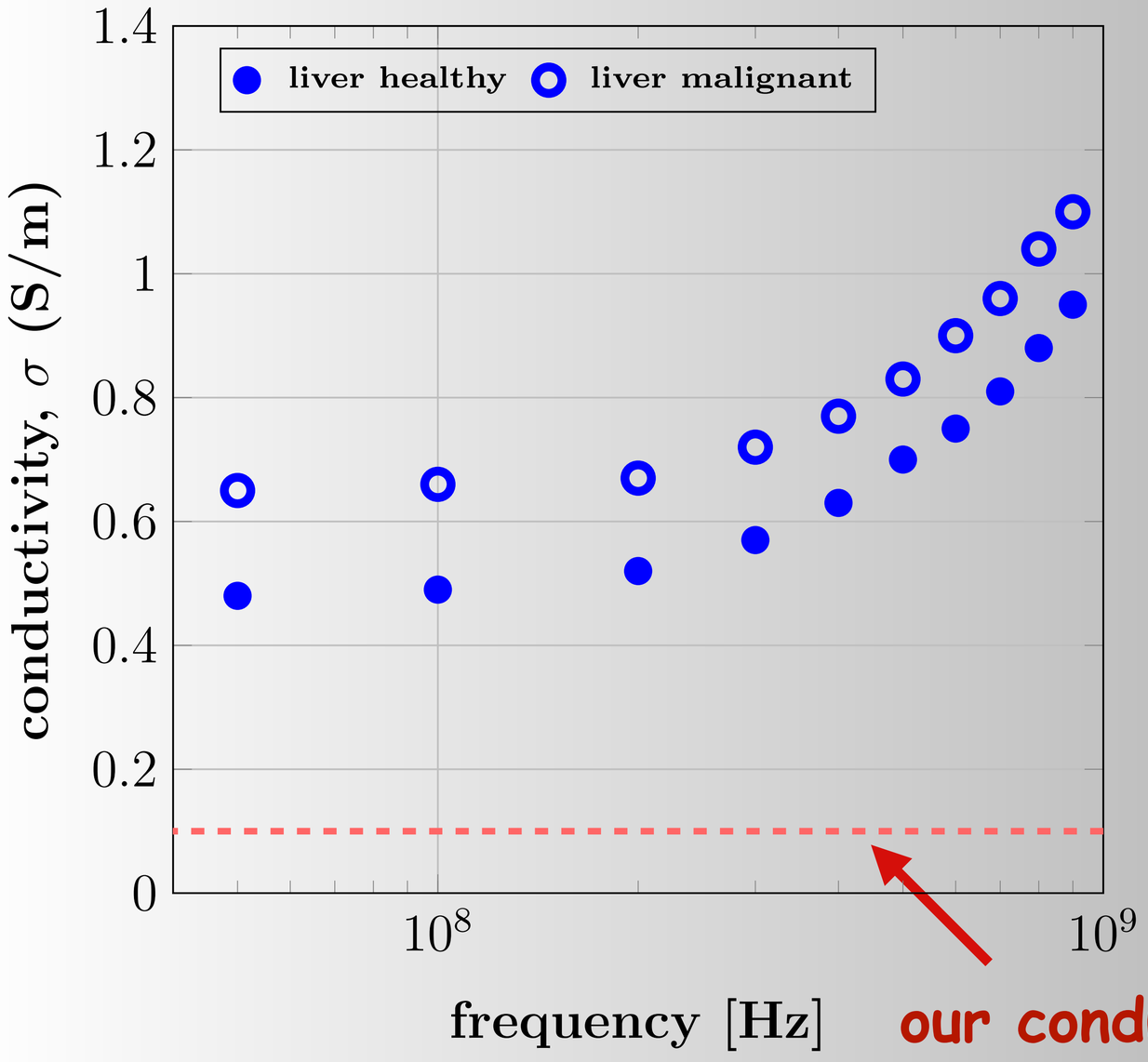
Our Method can penetrate skeleton and skull !!!

Dielectric Properties can revel abnormal Tissue properties !!!

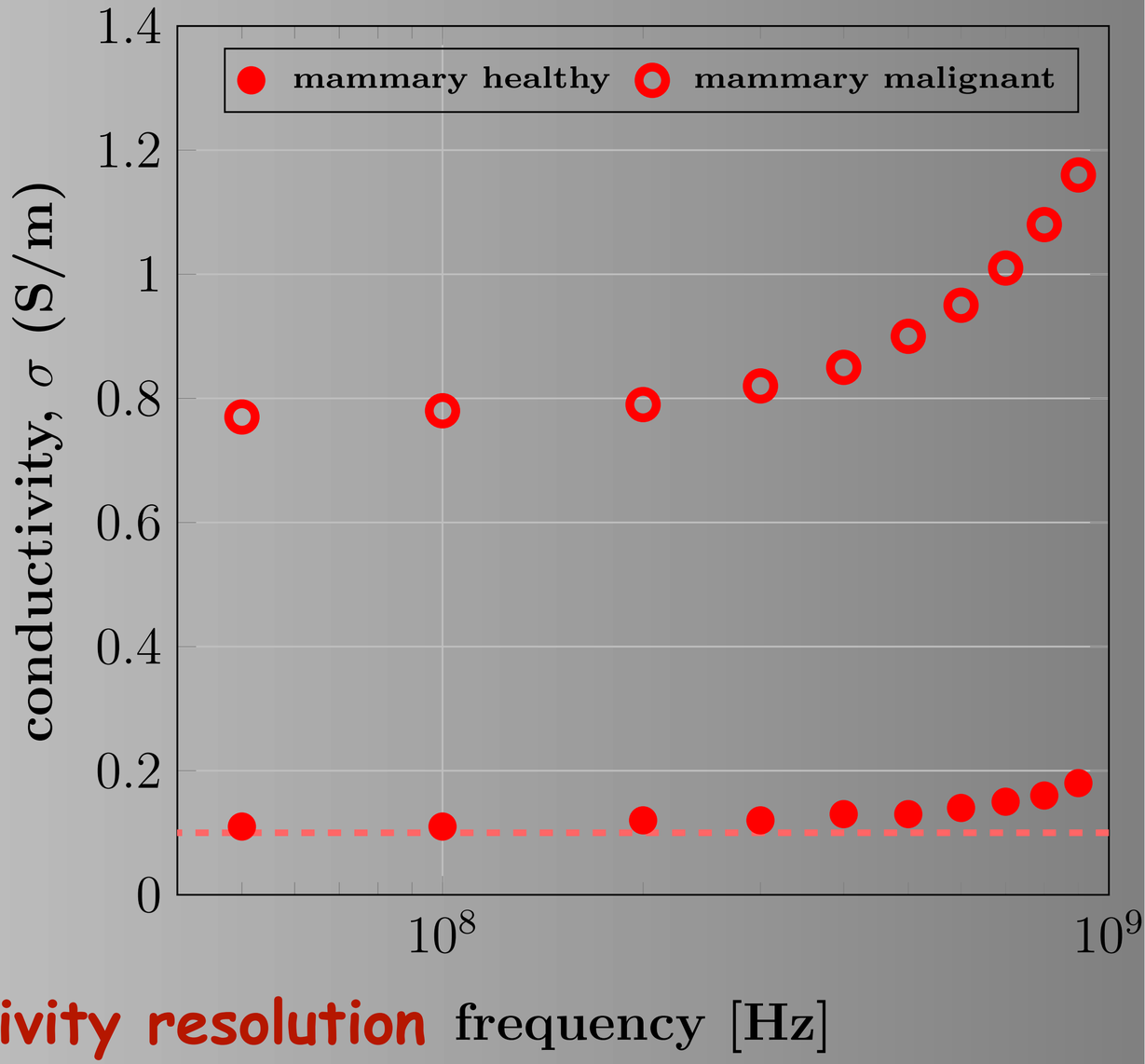


Iron displays high conductivity at high frequencies, allowing our method to detect the development of all types of tumors

Dielectric Properties can revel abnormal Tissue properties !!!

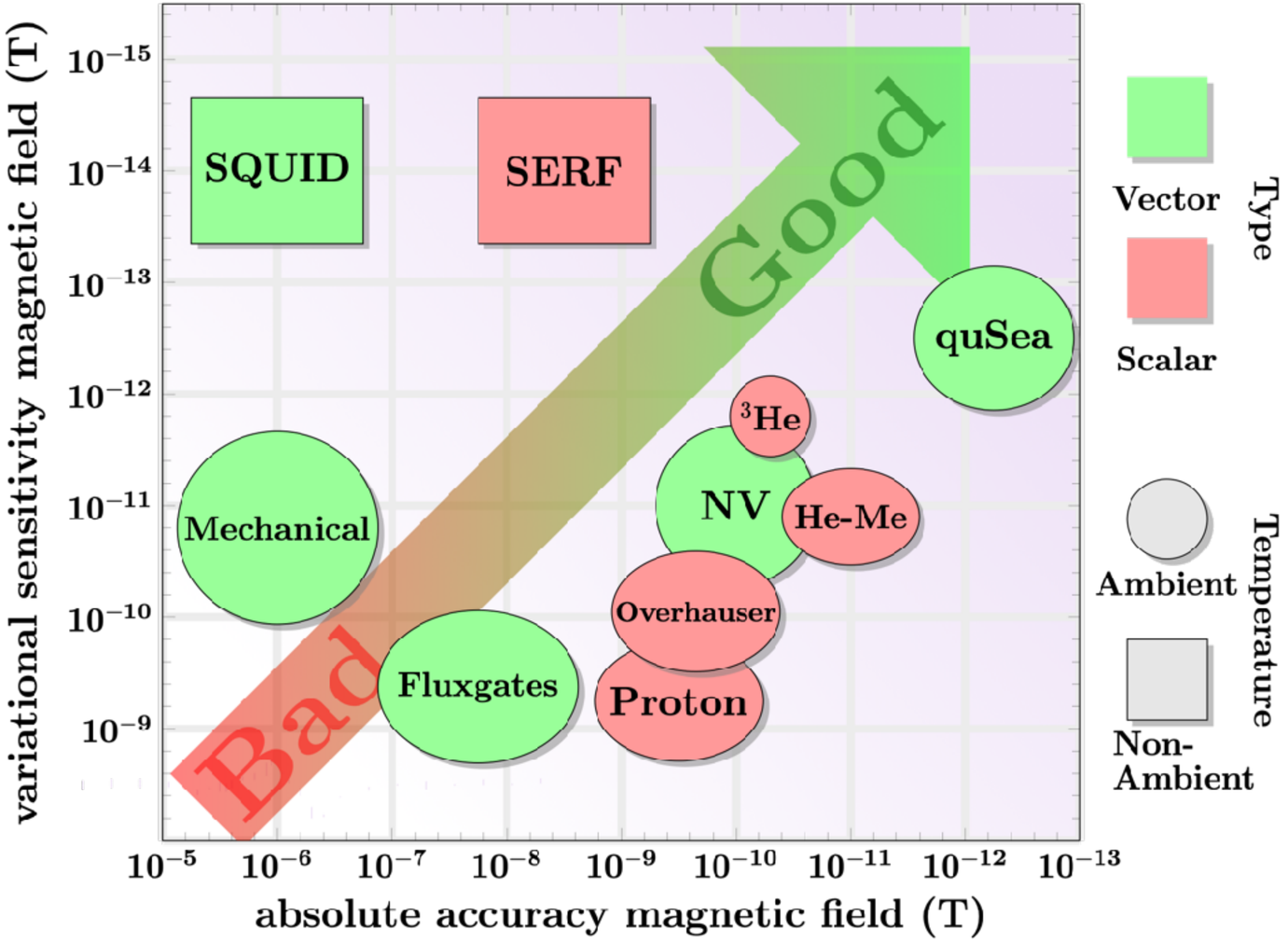


our conductivity resolution



A Single Imaging Modality for Cancer that is Non-Invasive !!!

State of the Art



1) High Sensitivity
2) Ambient -Temperature Operation
3) full Vector-Magnetometry Capabilities
4) large Dynamic Range
5) Absolute B field abilities (no calibration errors)
6) small, compact footprint (mm spatial resolution)

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