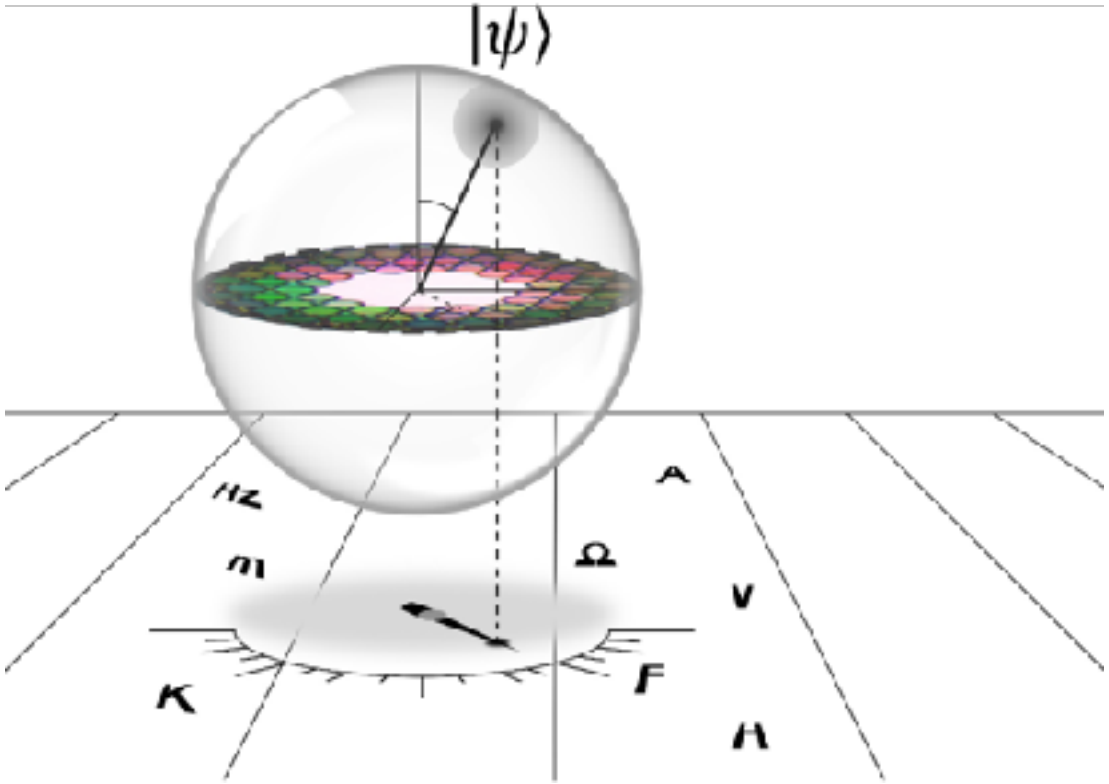
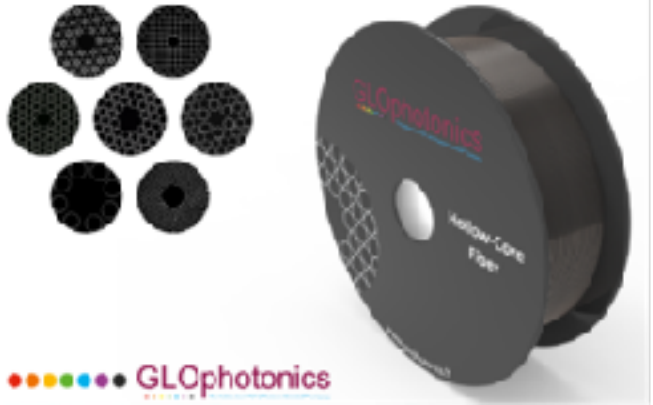
GLOphotonics

The Hollow-Core PCF & Photonic MicroCell™ company

Navigating the Quantum World with Magnetic Fields

Devang Naik, Lead scientist, BTU QuTech





GLOphotonics

GLOphotonics

The company

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*.

MULTISECTORIAL PRODUCT MIX

GLOphotonics HCPCF and PMC technology is equally a platform key-enabling technology.

A feature, reflected in GLO photonics products, service and offe

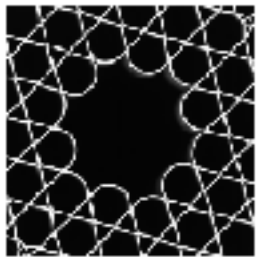
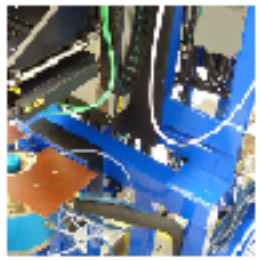
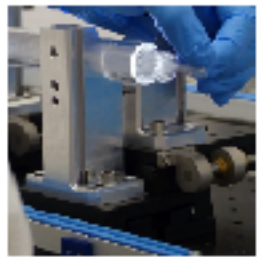
- **HOLLOW CORE PHOTONICS CRYSTAL FIBER & PHOTONIC MICROCELL**
- **BEAM DELIVERY**
- **PULSE COMPRESSION**
- **FREQUENCY CONVERSION & LASERS**
- **FREQUENCY REFERENCES**
- **LOW LATENCY DATACOM**
- **TECHNOLOGY SOLUTIONS**

GLOphotonics

TECHNOLOGY

HCPCF

Hollow Core Photonic Crystal Fiber

What it is

HCPCF outstands by guiding light in a hollow channel surrounded by a microstructured cladding.

GLO is a pioneering industrial player in this field by offering its partners varied and bespoke HCPCF.

How it is made

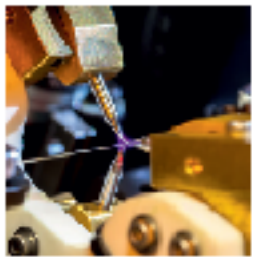
HCPCF are produced using a set of special techniques in making its preform and in its drawing process.

GLO enjoys fiber drawing infrastructure purposely design for HCPCF requirements.

PMC™

Photonic Micro-Cell





What it is

A Photonic Micro-Cell (PMC) is a length of HCPCF filled with a gas

in a controllable fashion and hermetically sealed.

PMC offers highly strong gas-light interaction

How it is made

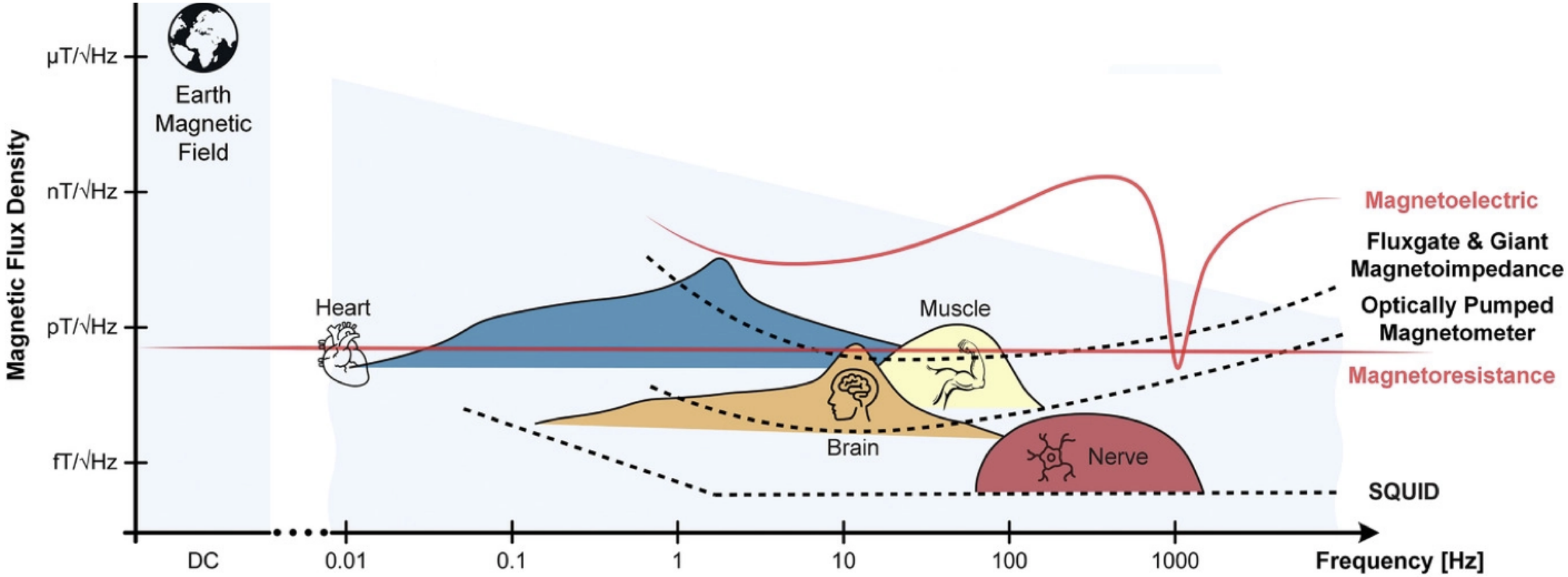
GLO enjoys a large number of processes in evacuating its HCPCF or filling it with a variety of gases and at different pressures.

The PMC technology relies on glass post-processing, such as splicing, fusing, engraving, end capping.

The PMC terminations are designed and shaped to accommodate specific applications or required standards.

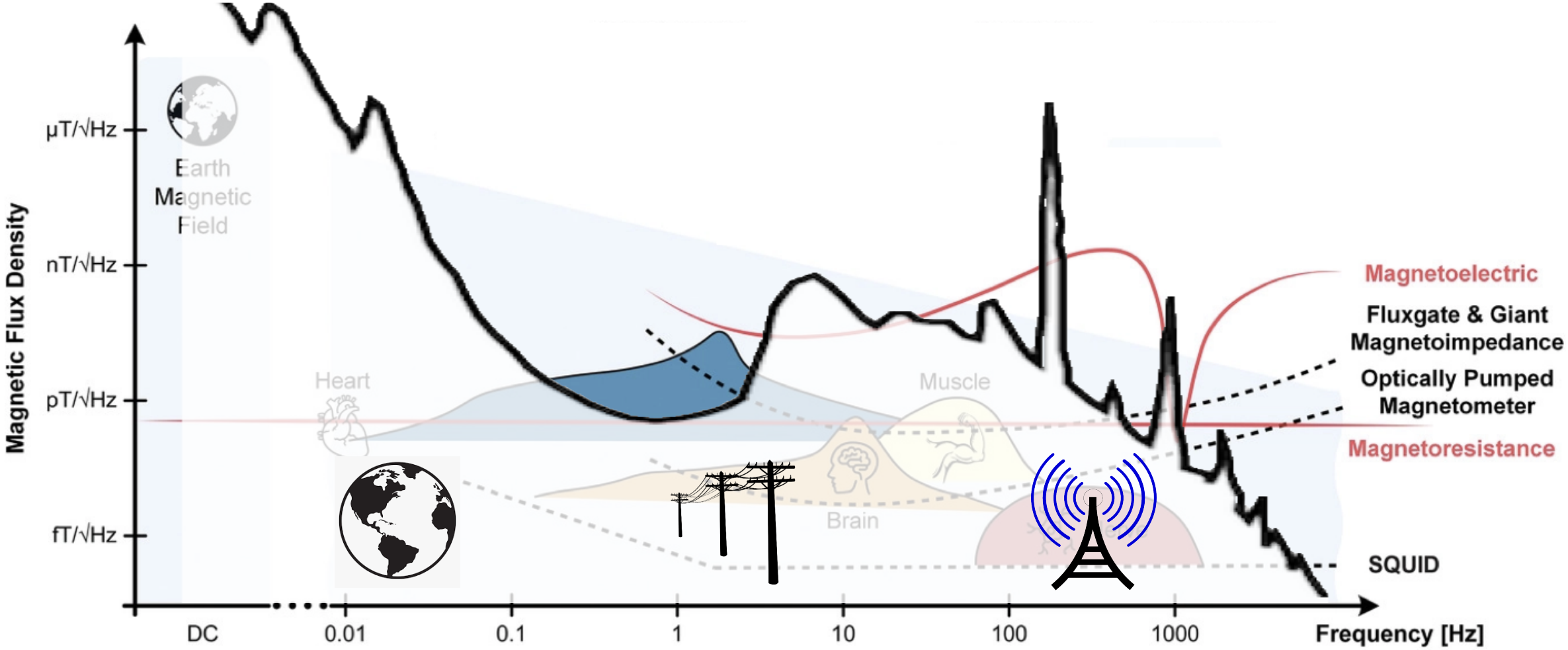
In some specific applications, we even coat the PMC inner core with smart coatings.

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



GLOphotonics

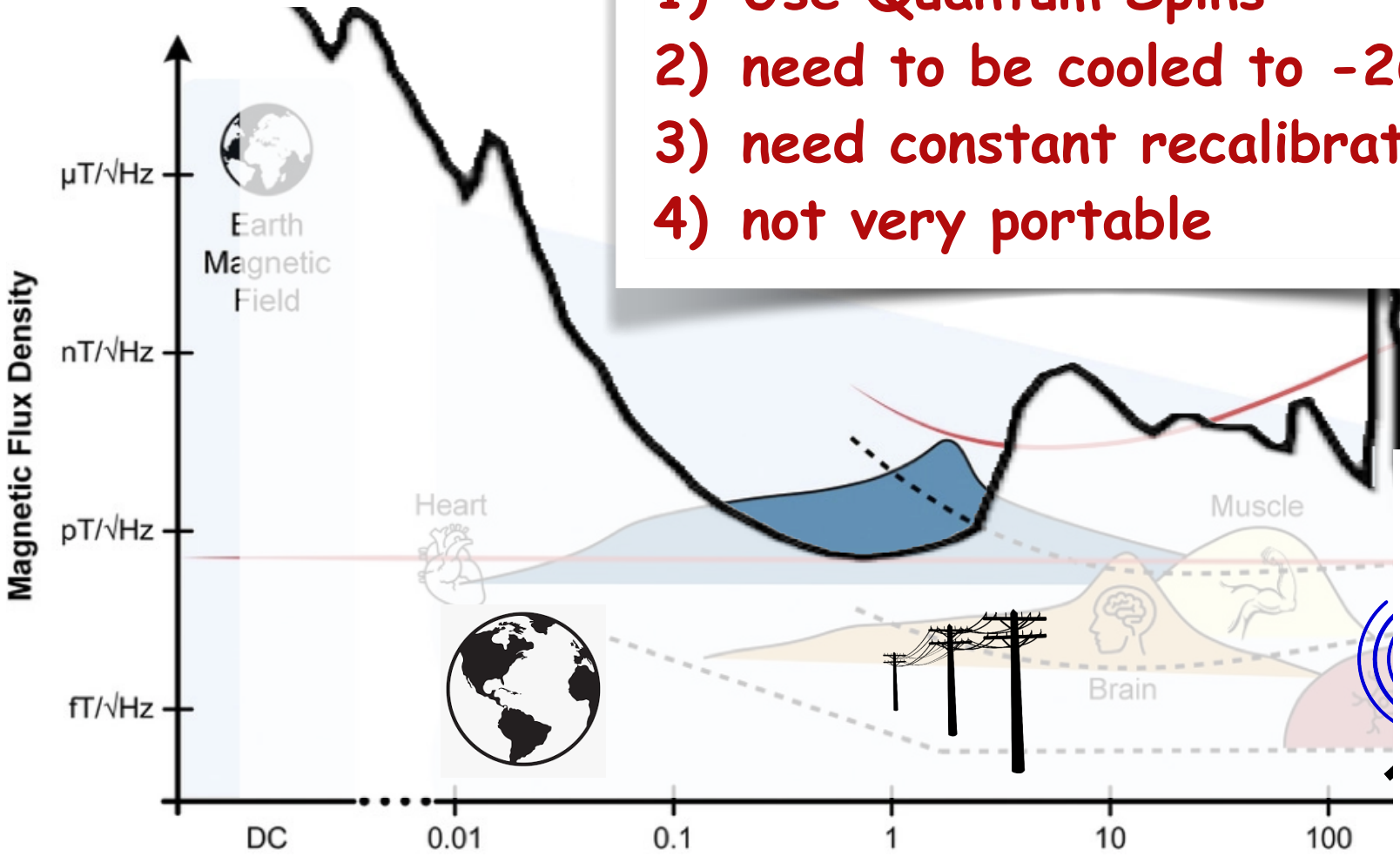
However the signals are buried deep within noise …



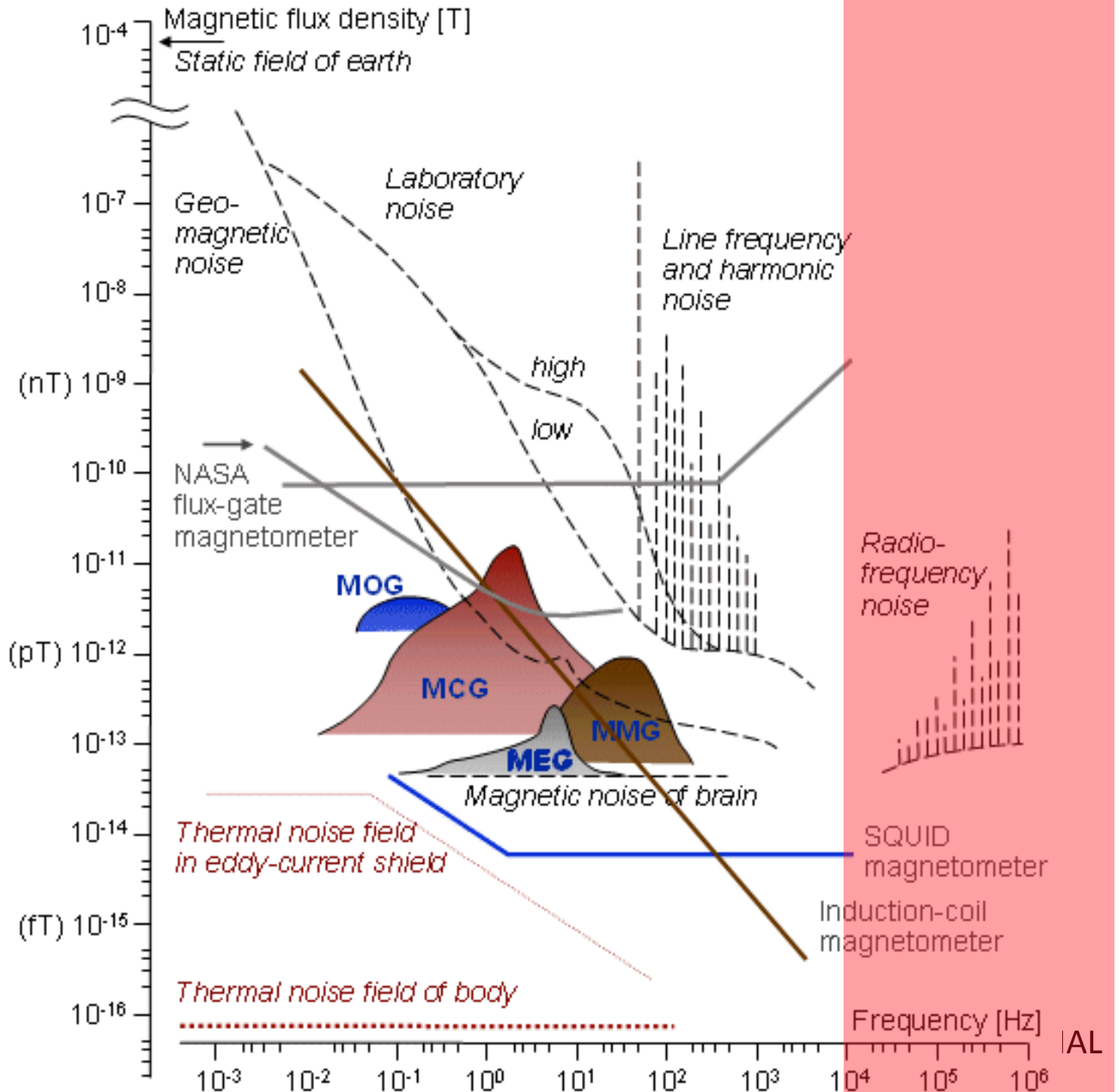
GLOphotonics

However the

1) Use Quantum Spins
2) need to be cooled to -269 C
3) need constant recalibration
4) not very portable



GLOphotonics



Un-explored Territory

with High Signal-to-Noise

Application

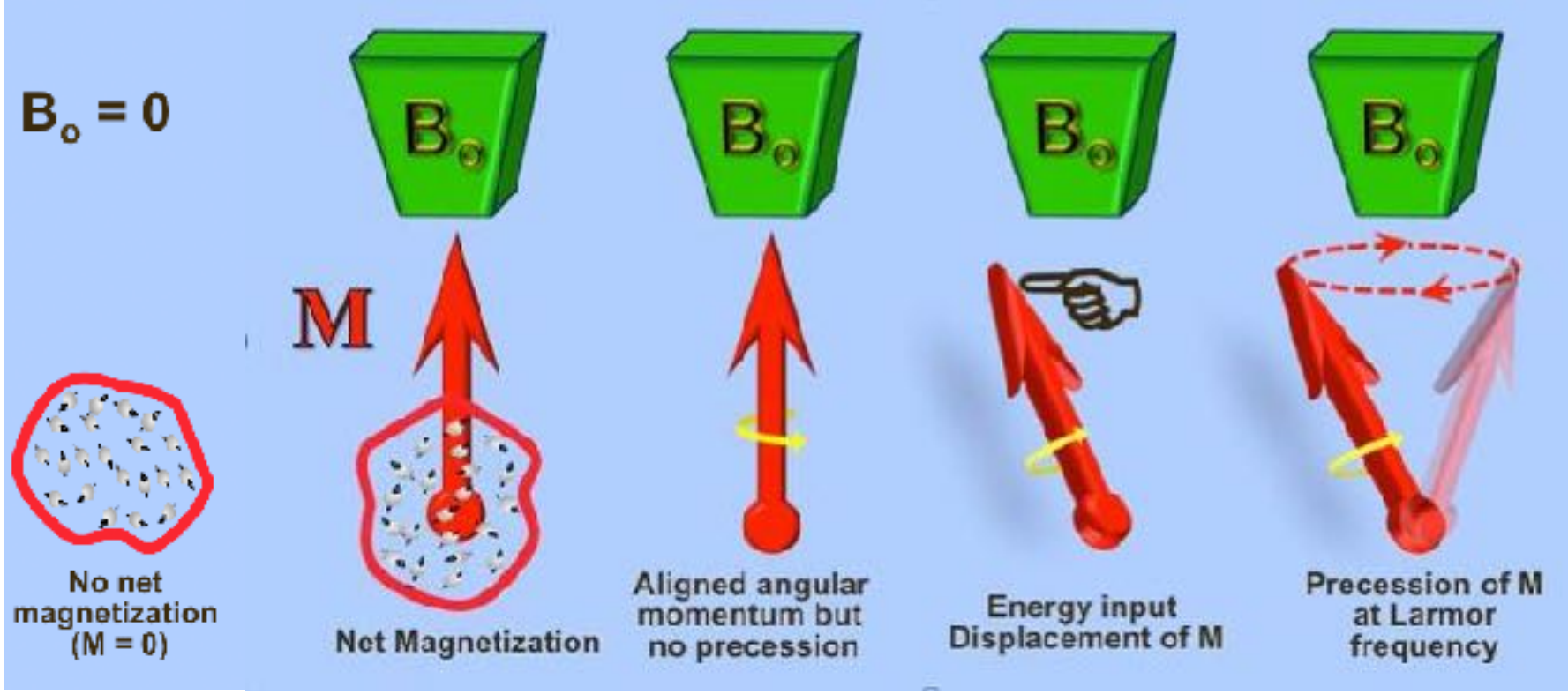
1) Medical-Imaging
2) Search for Natural Resources
3) Geology
4) Military
5) Geolocation

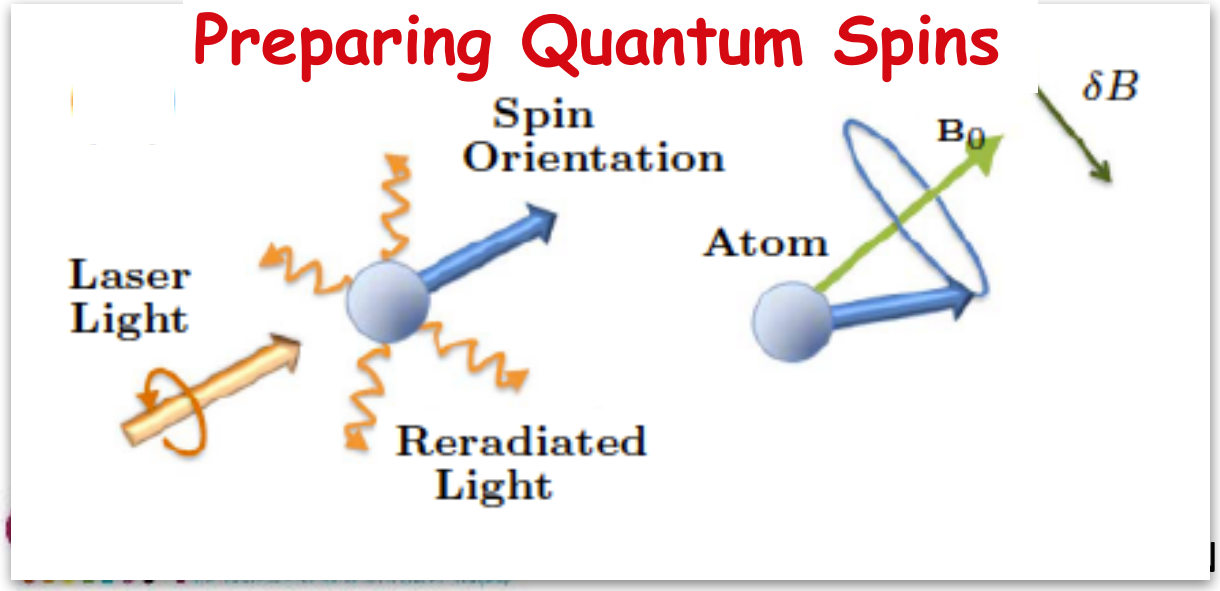
Biomagnetic signals

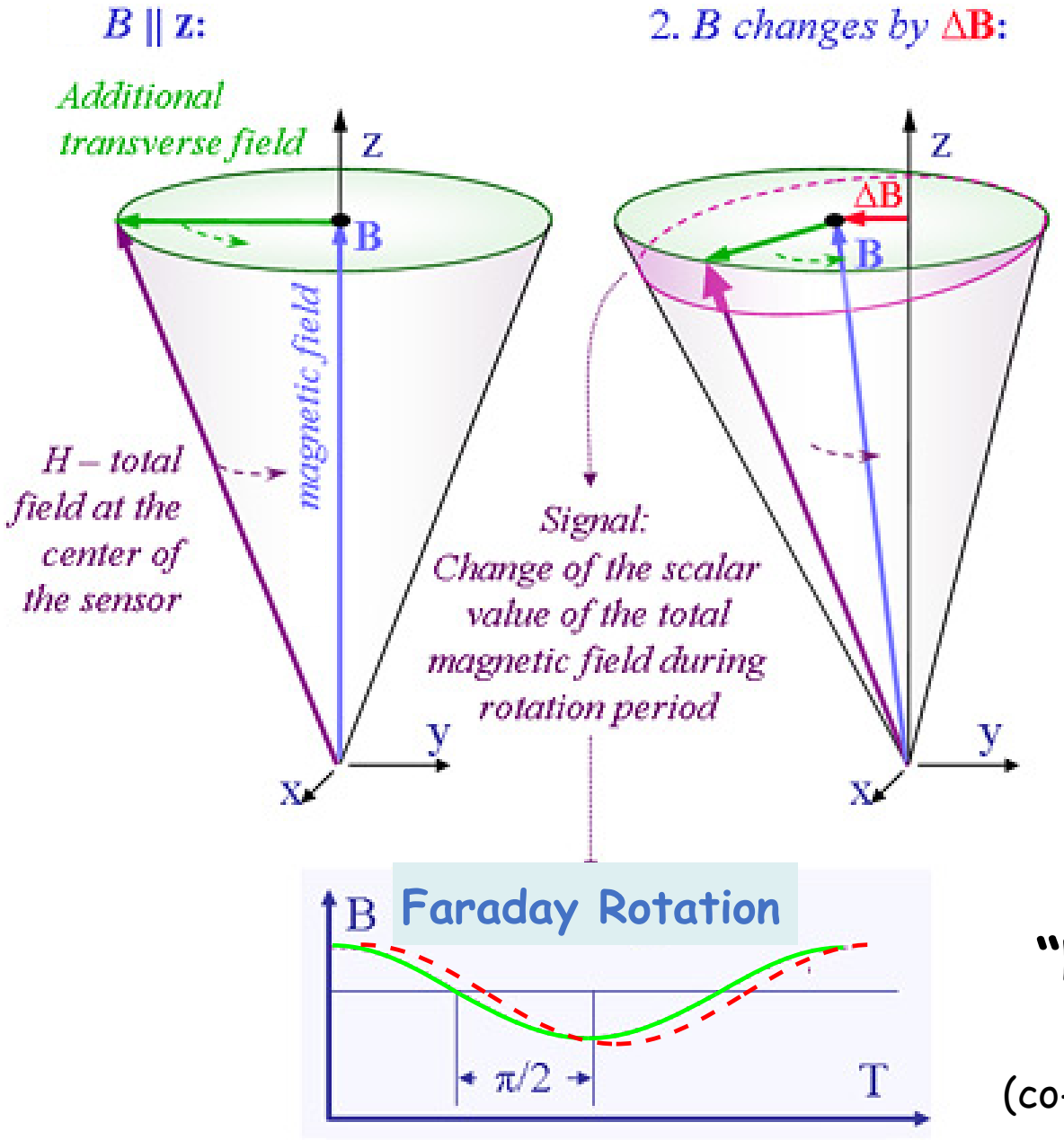
Noise fields

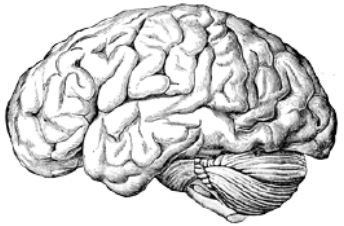
Equivalent input noise

Thermal noise fields


$B_o = 0$
B_o
B_o
B_o
B_o
M
No net magnetization (M = 0)
Net Magnetization
Aligned angular momentum but no precession
Energy input Displacement of M
Precession of M at Larmor frequency


Preparing Quantum Spins
Spin Orientation
Laser Light
Reradiated Light
Atom
B_0
δB





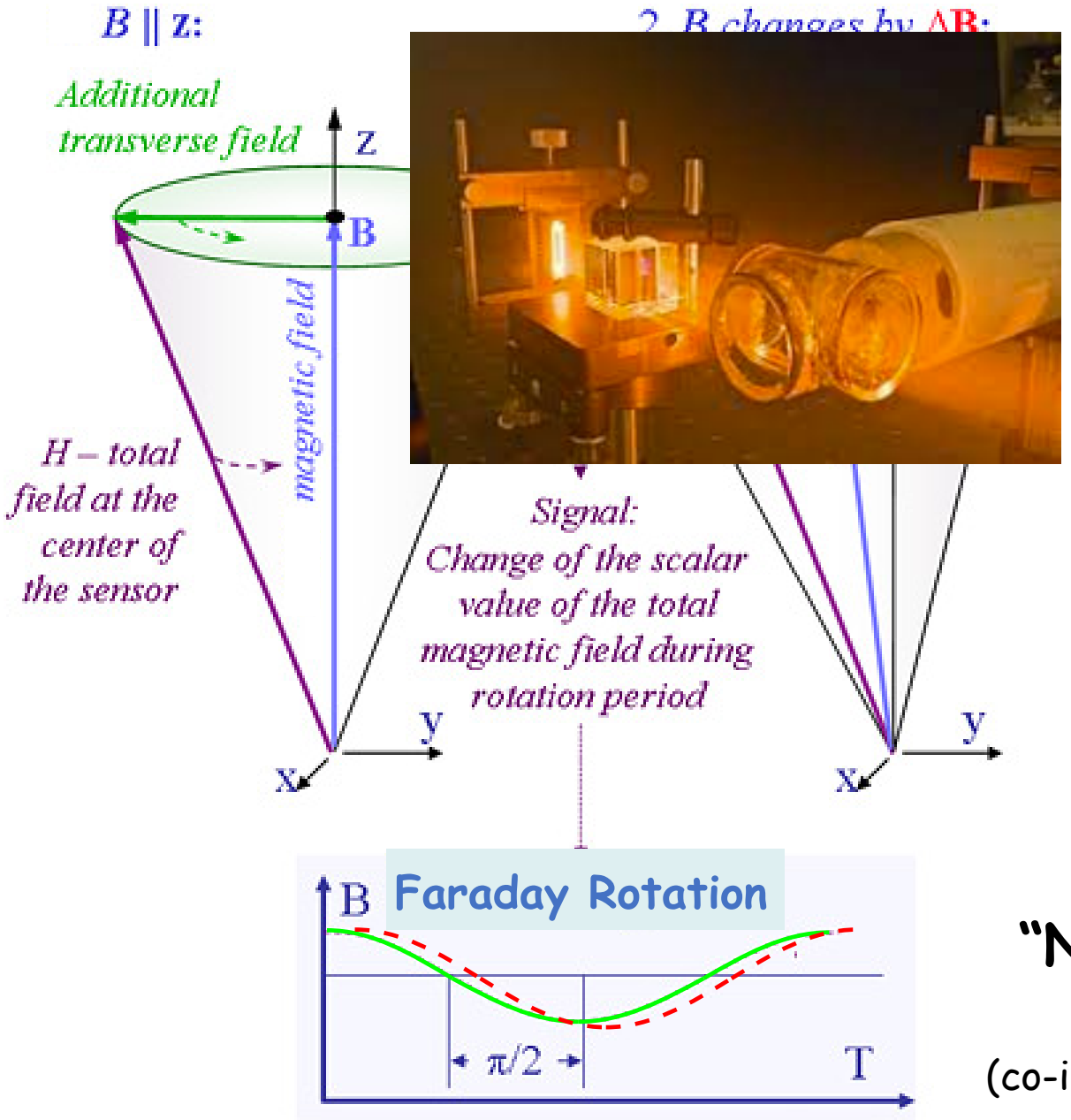
Convert Magnetic Field to Frequencies, which can be measured with metrological precision

"Never measure anything but frequency!"

Arthur Schawlow

(co-inventor of laser with Townes, winner of Nobel Prize in 1981)

GLOphotonics



1) Using Quantum Spin allows $fT/\sqrt{(Hz)}$ sensitivity

However

2) frequencies < 10 kHz

3) limited by fundamental quantum noise

4) limited by spatial sensitivity

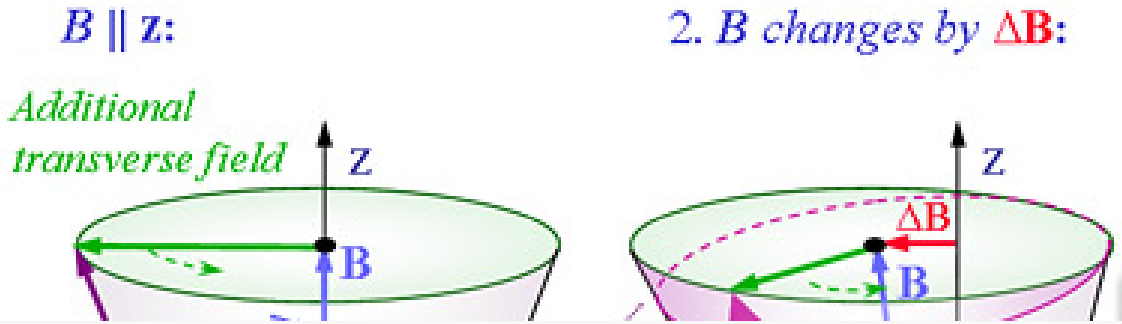
"Never measure anything but frequency!"

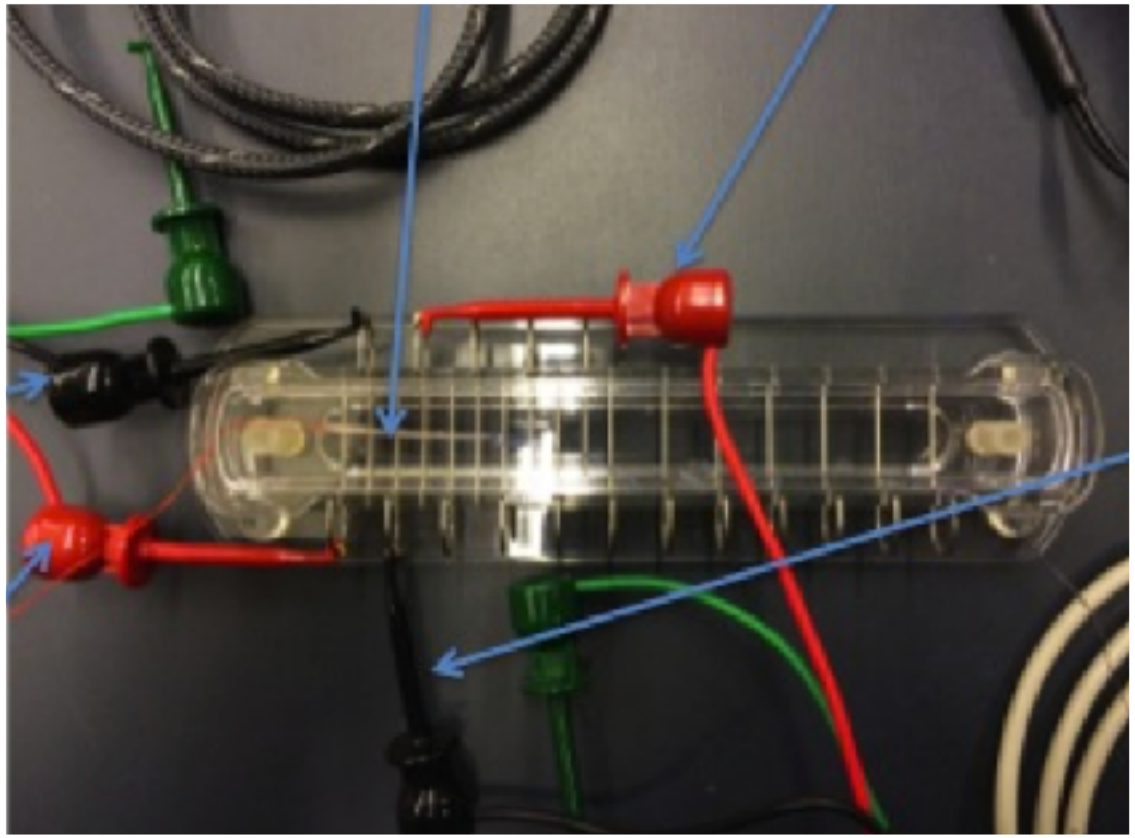
Arthur Schawlow

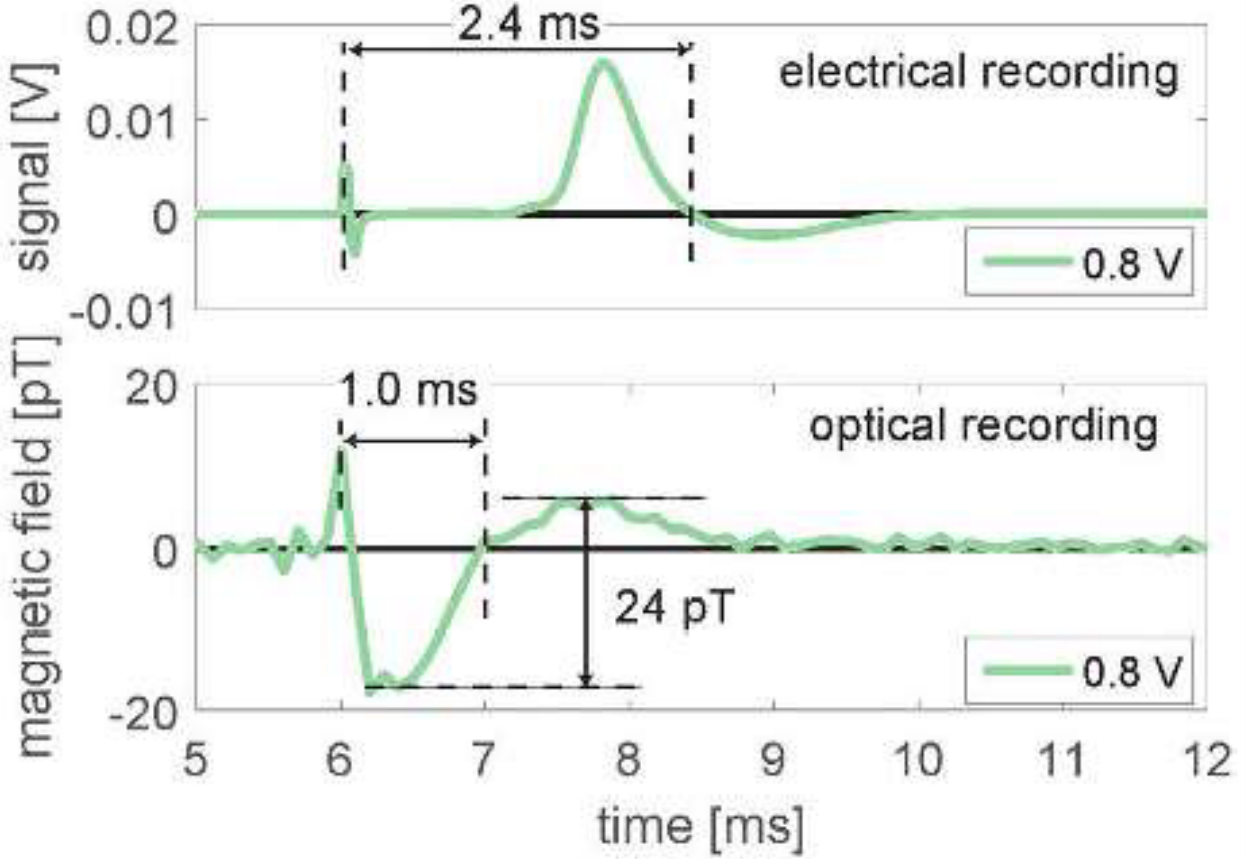
(co-inventor of laser with Townes, winner of Nobel Prize in 1981)

GLOphotonics

Proof-of-Principle: Measuring B field of neurons with entangled atoms

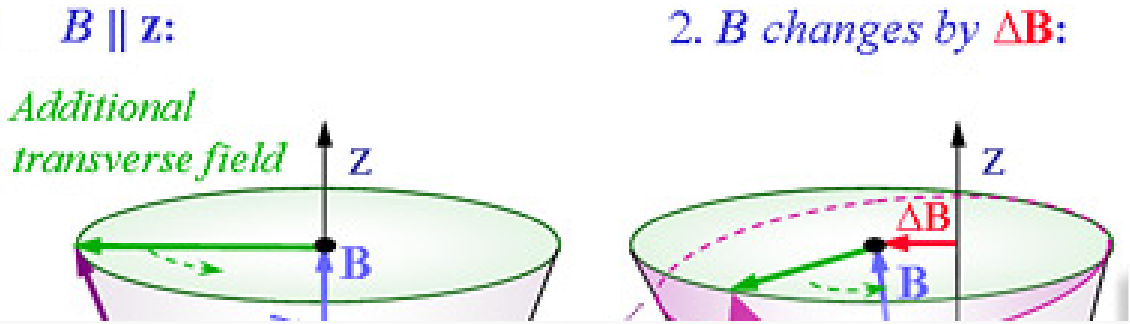


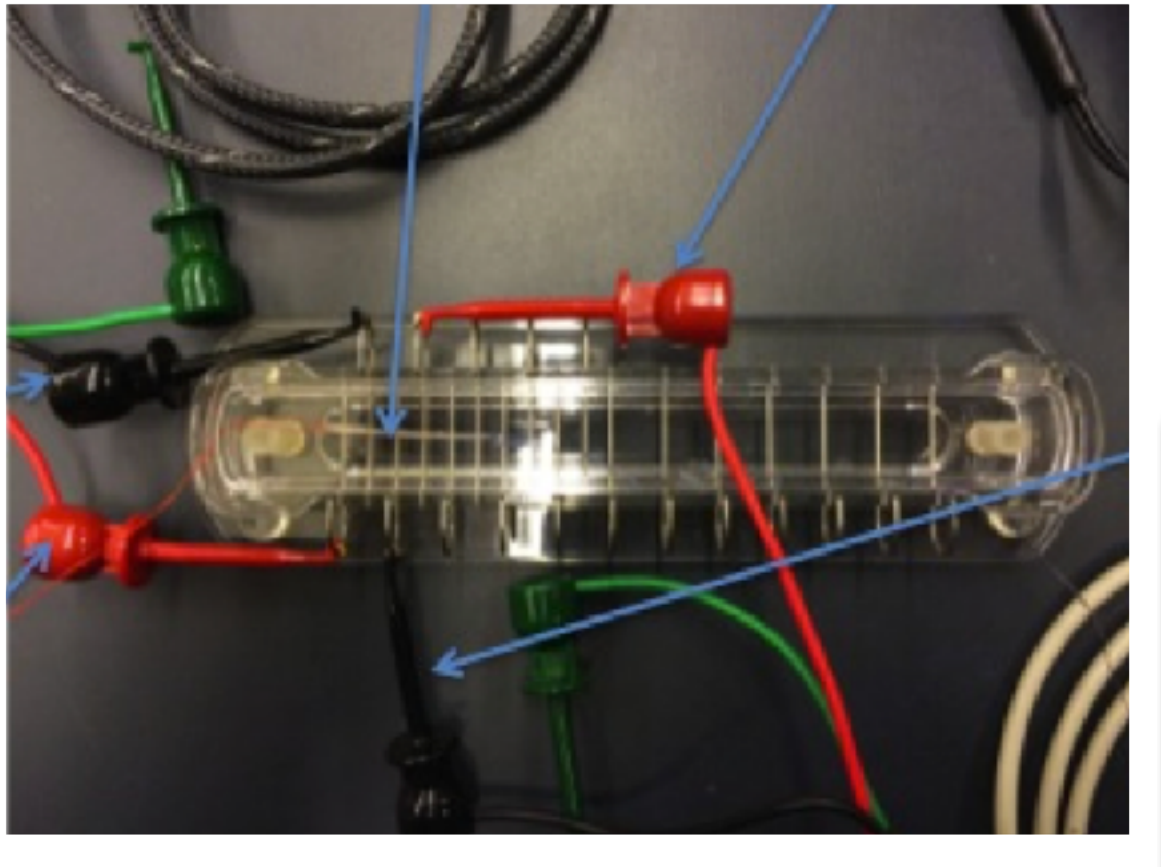




GLOphotonics

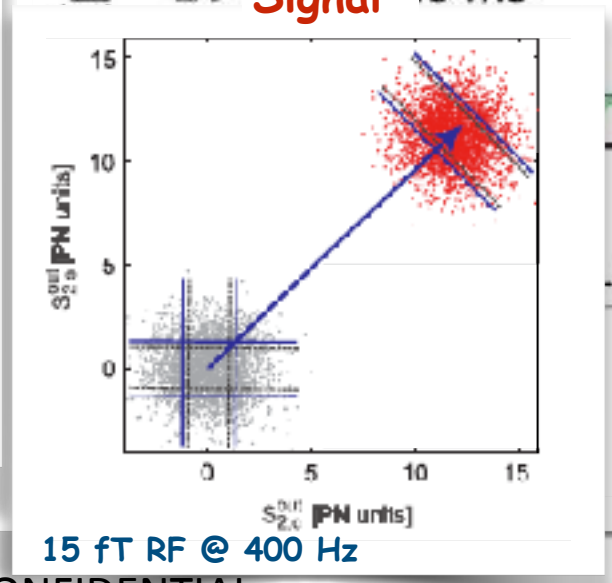
Proof-of-Principle: Measuring B field of neurons with entangled atoms





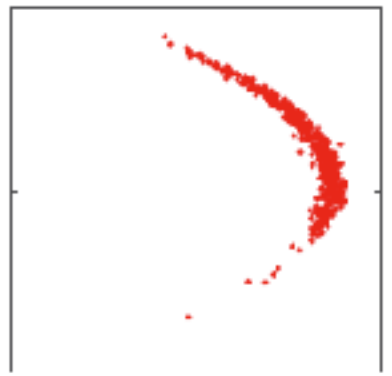
1) Beyond Standard Quantum Limit Sensitivities !!!
2) High Frequencies

Signal



15 fT RF @ 400 Hz

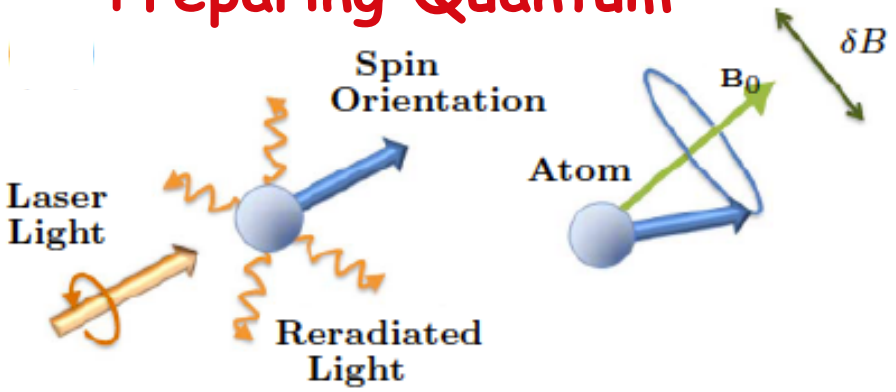
Spin Squeezing



GLOphotonics

The Importance of Atom-Light Interactions

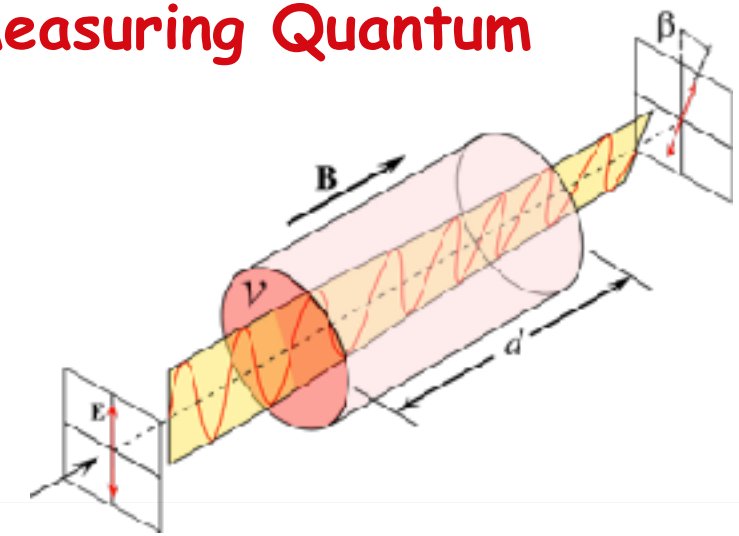
Preparing Quantum

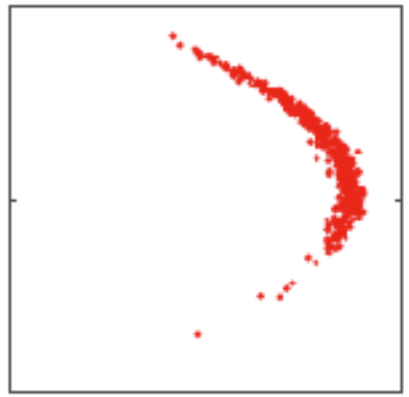


Every Step in the process requires high atom-light interactions:

1) Preparing Quantum Spins
2) Measuring Quantum Spins
3) Beyond Quantum Limit

Measuring Quantum





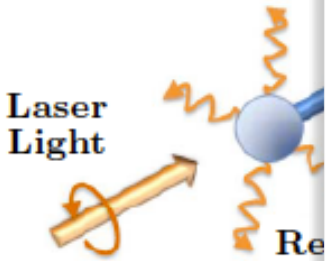
Spin Squeezing

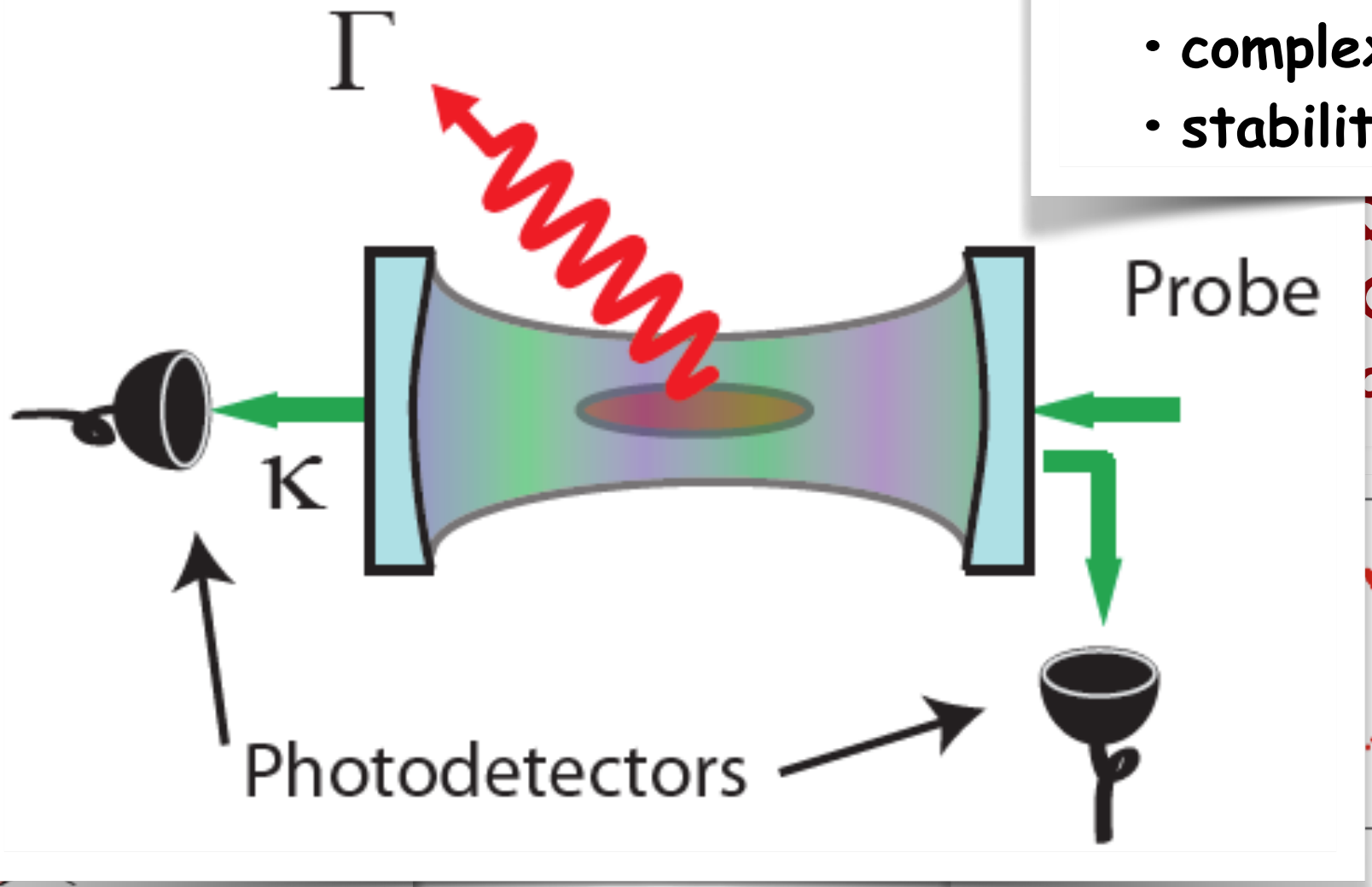
The Importance of Atom-Light

Cavity Enhancement:

- factors of 100,000
- complex locking
- stability issues

Prepari



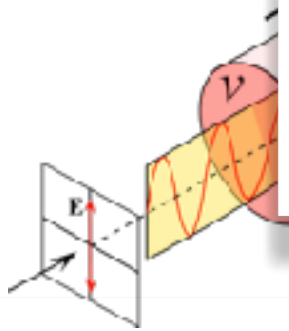


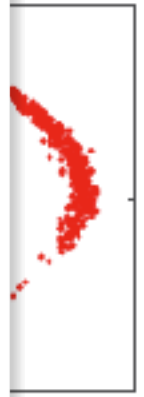
Quantum Spins

Quantum Spins

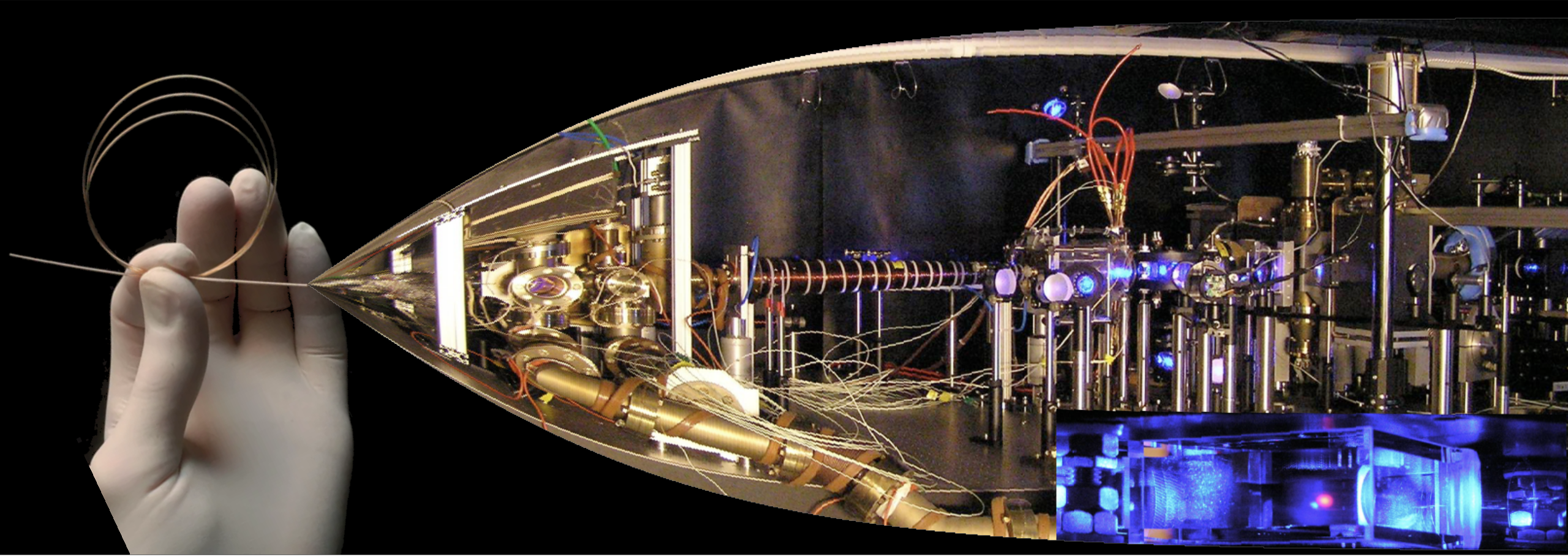
antum Limit

Measuring G





Spin Squeezing



By confining light + atoms on length scales over kms, we can arrive at Orders of Magnitude Larger Optical Depth in a compact, simple platform

- volume reduced from m^3 to 100s um^3 !!!
- no cavity enhancement needed

GLOphotonics

GLO is well positioned for Quantum 2.0 Revolution

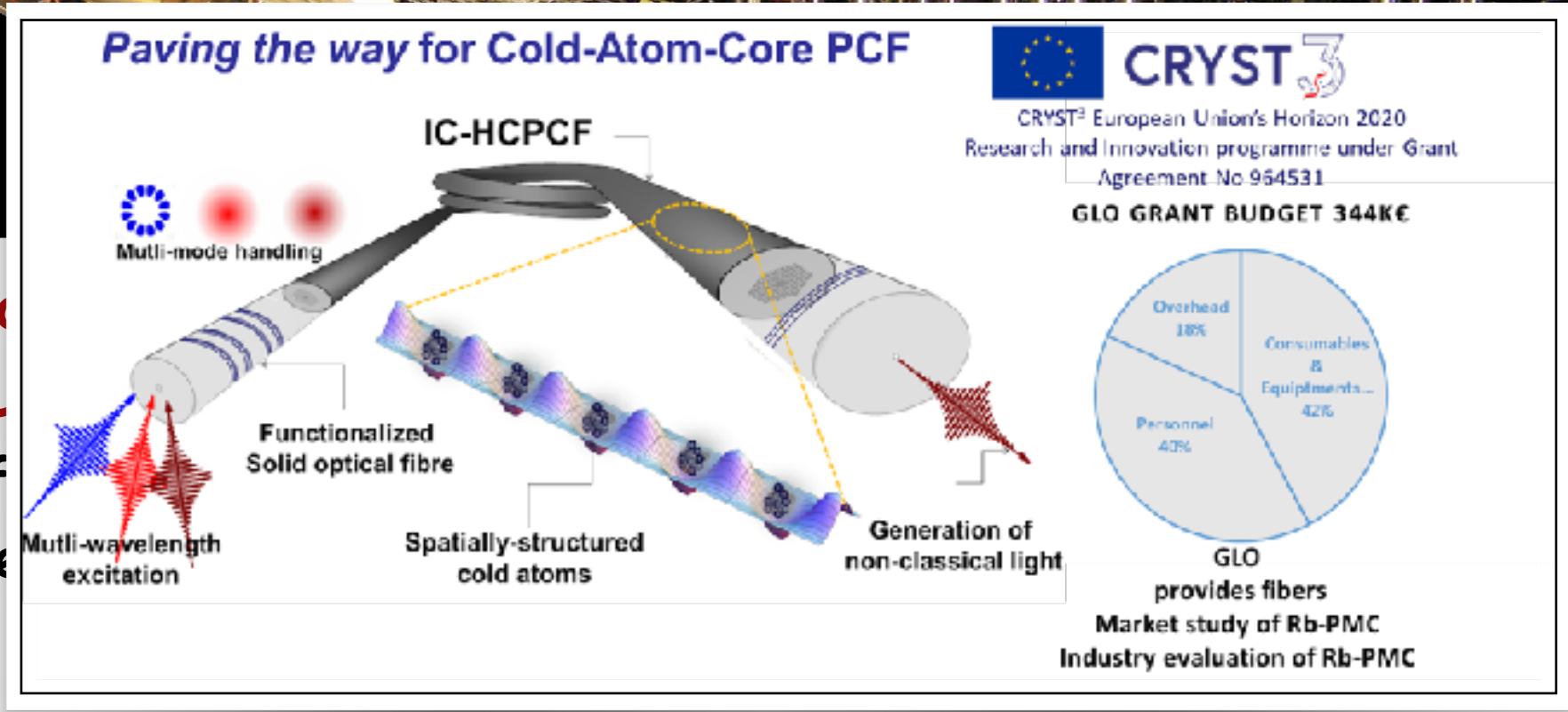
The Commercial Quantum Sensors utilizing Entanglement/Squeezing !!!

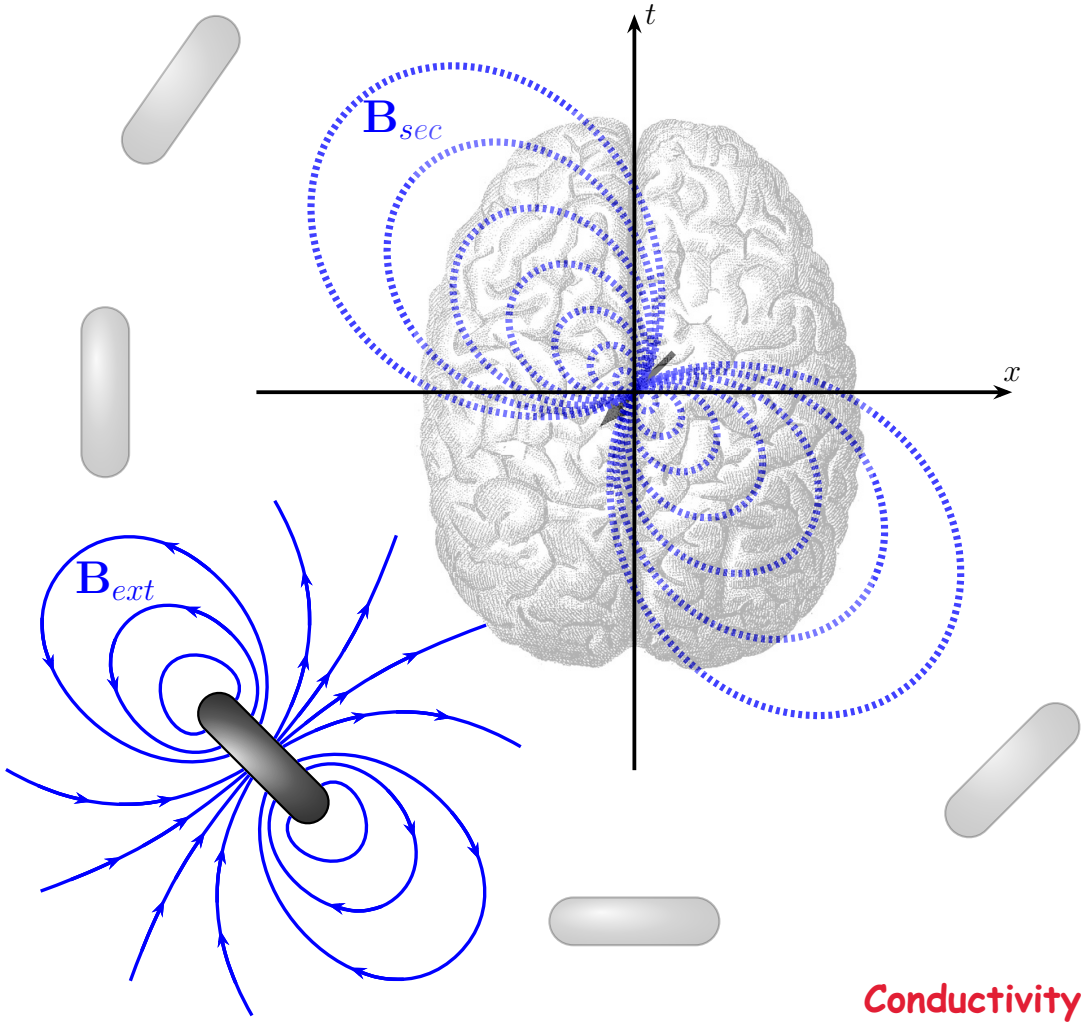
By confining light + ato

Orders of Magnitude L

- volume reduced f
- no cavity enhance

GLOphotonics



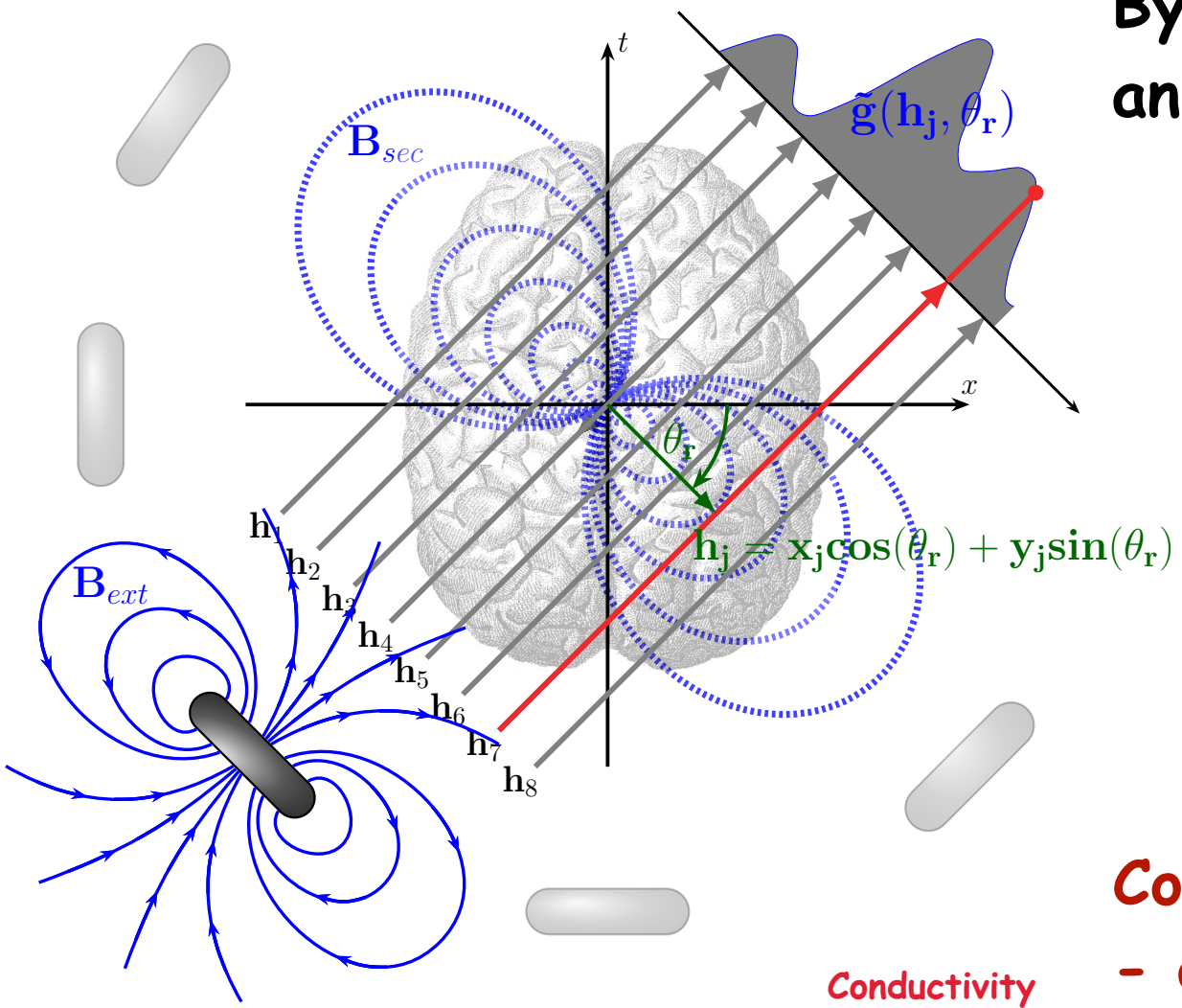


Conductivity

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

permitivity permeability

GLOphotonics



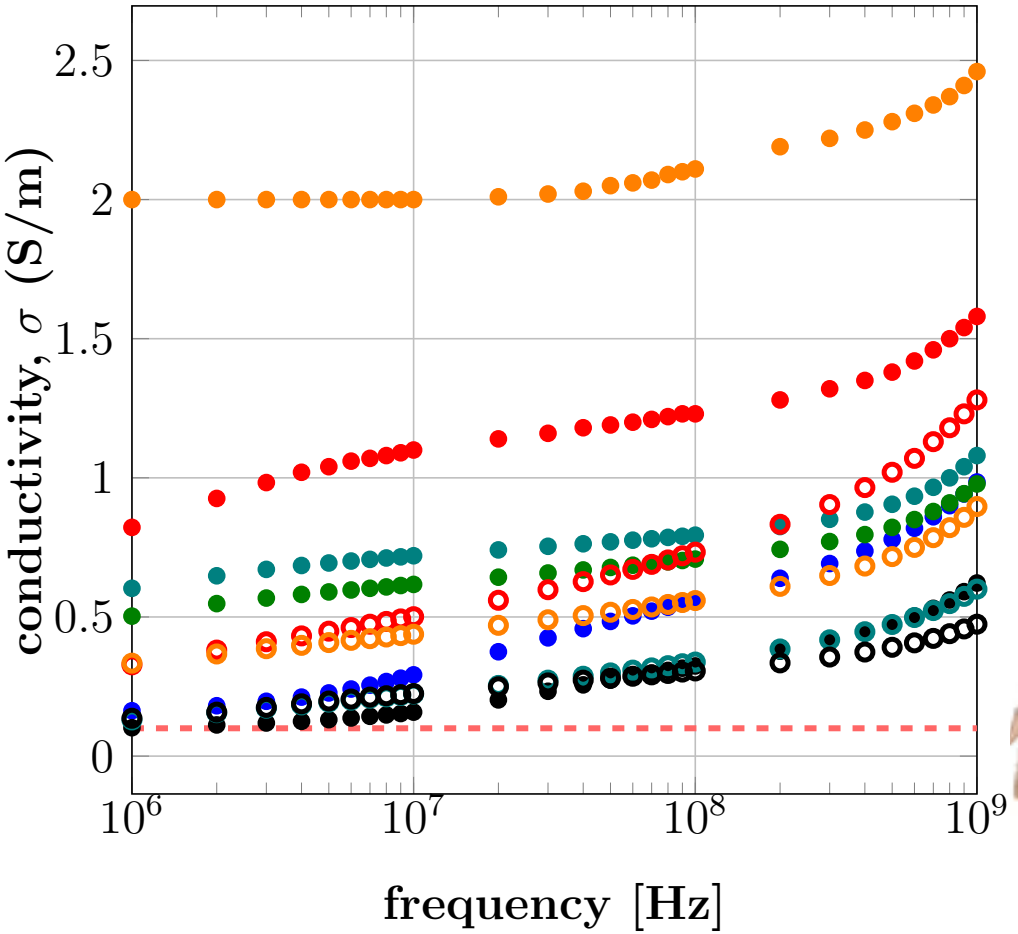
By taking our lab level technology and implementing in all-fibered PMC

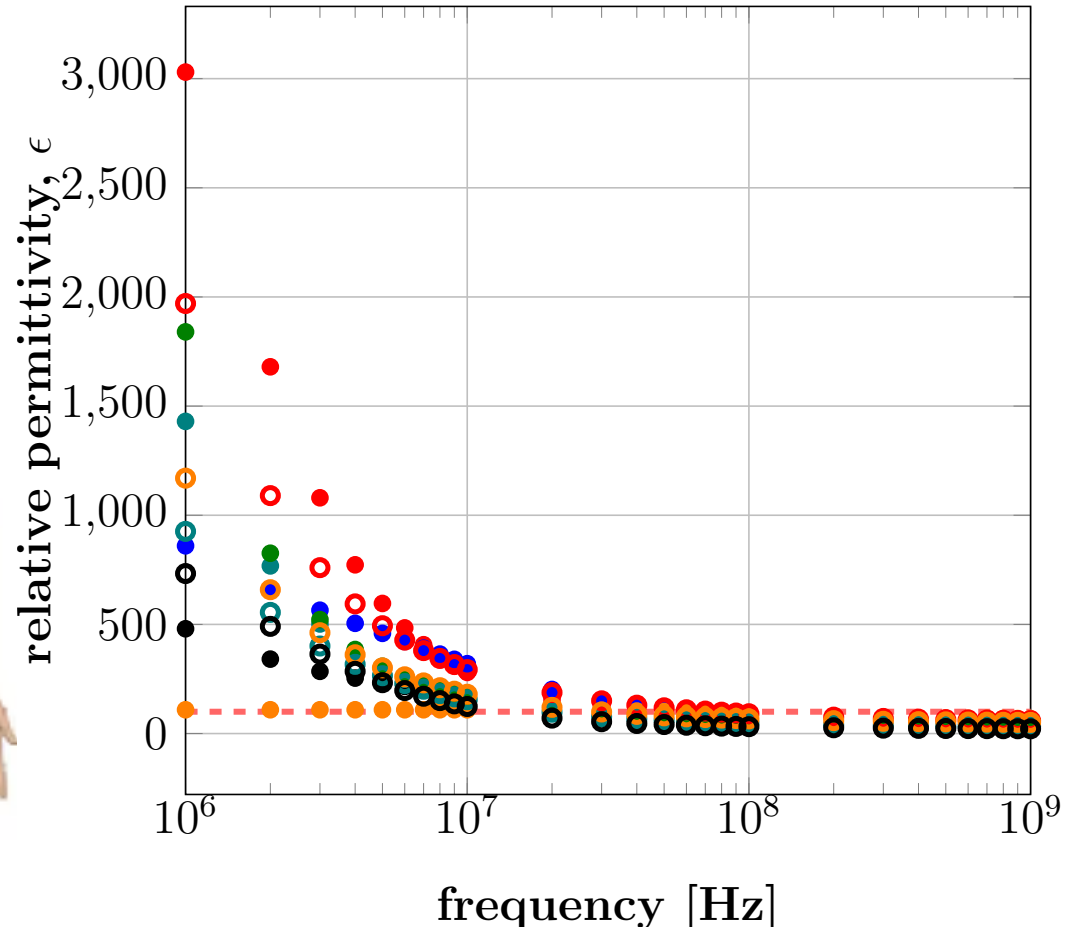
Conductivity 90 degrees out of phase - allows measurement via homodyne !!!

Conductivity

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

GLOphotonics

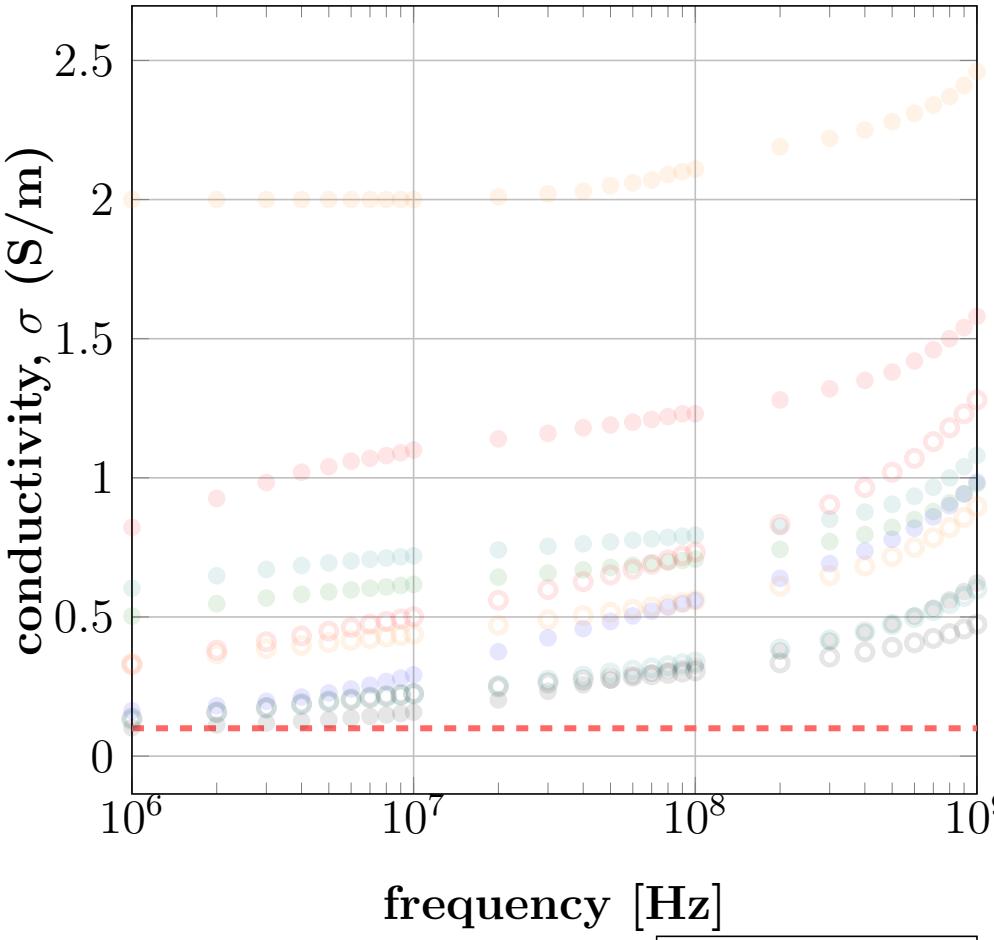


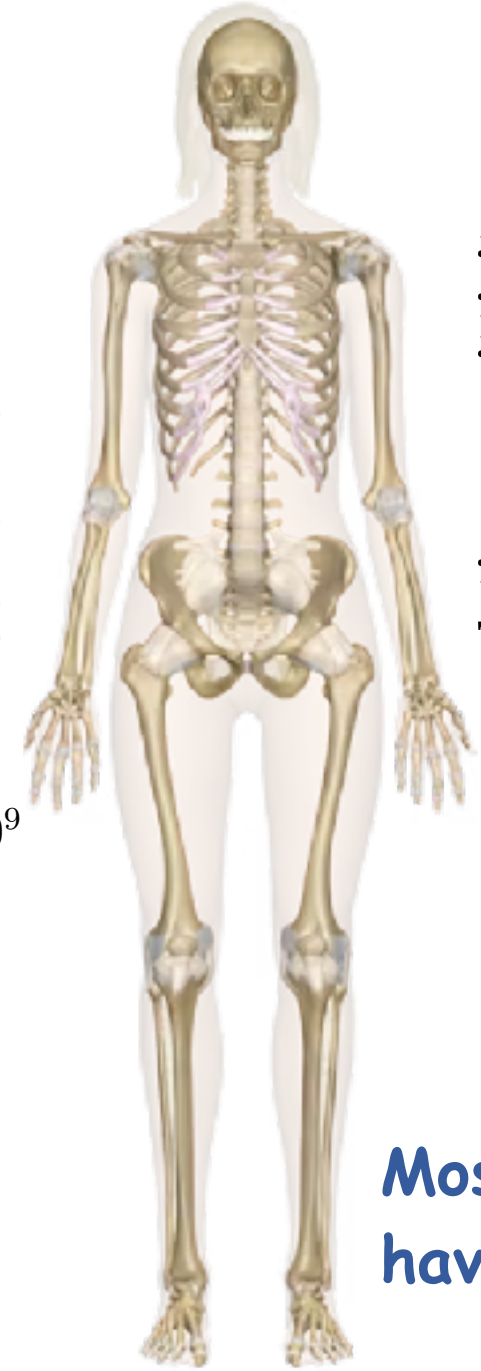


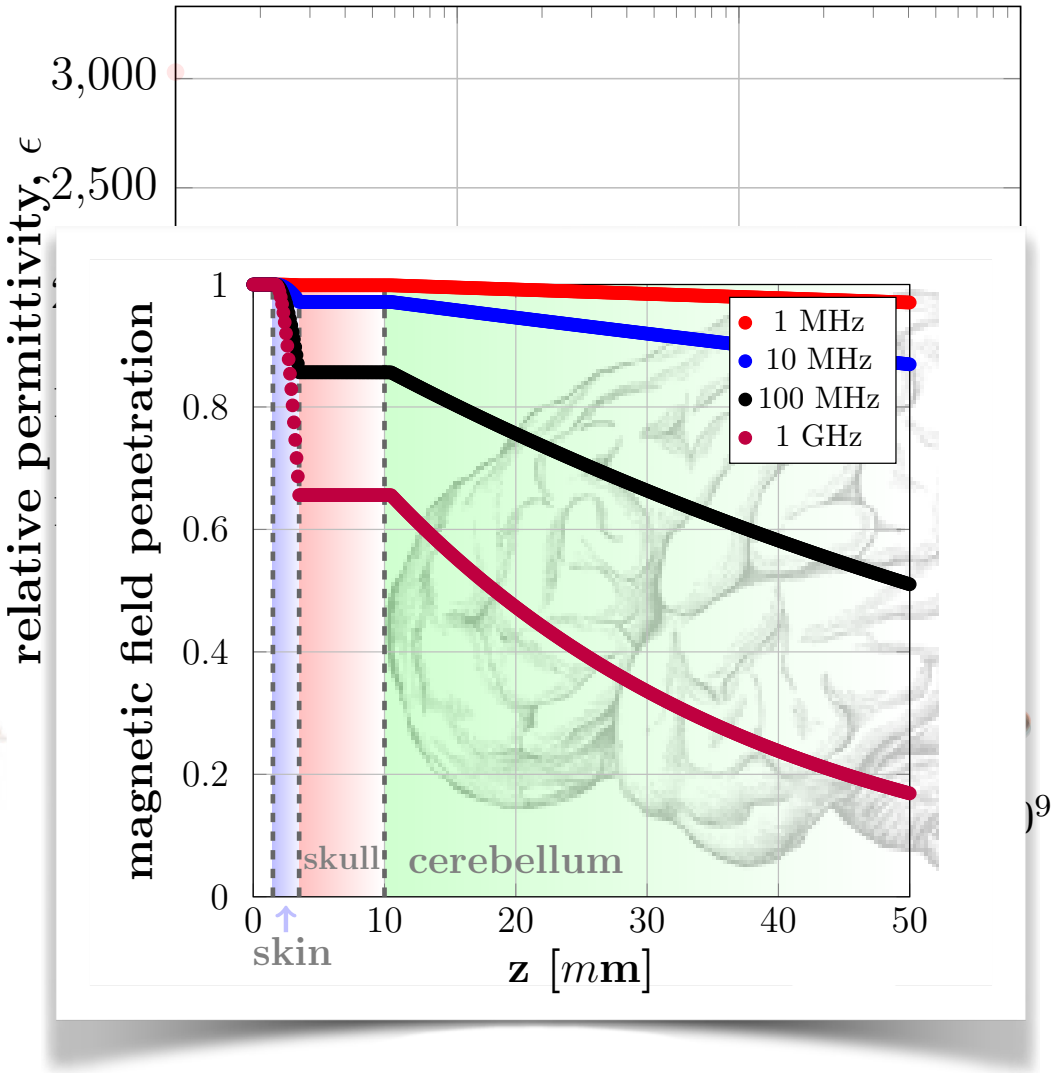
Current Medical Diagnostic Technology such as MRI measure only water:

We aim to offer tissue specificity !!!

GLOphotonics

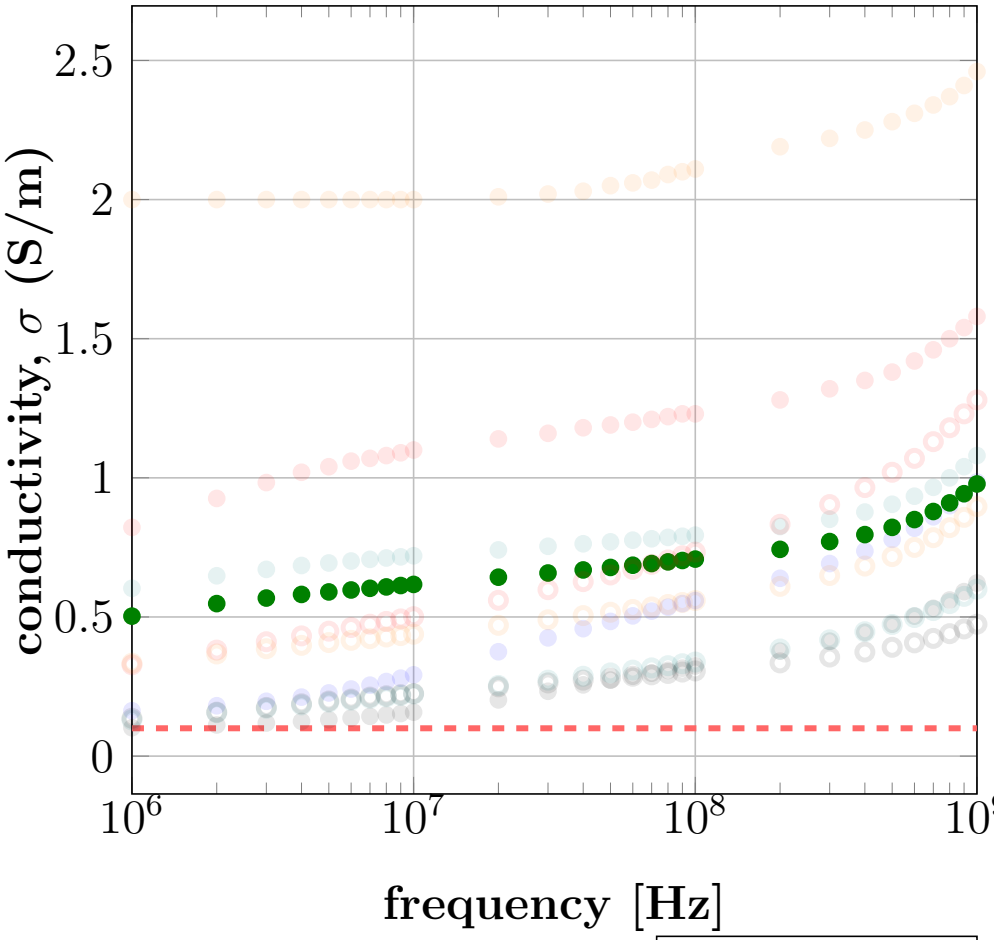


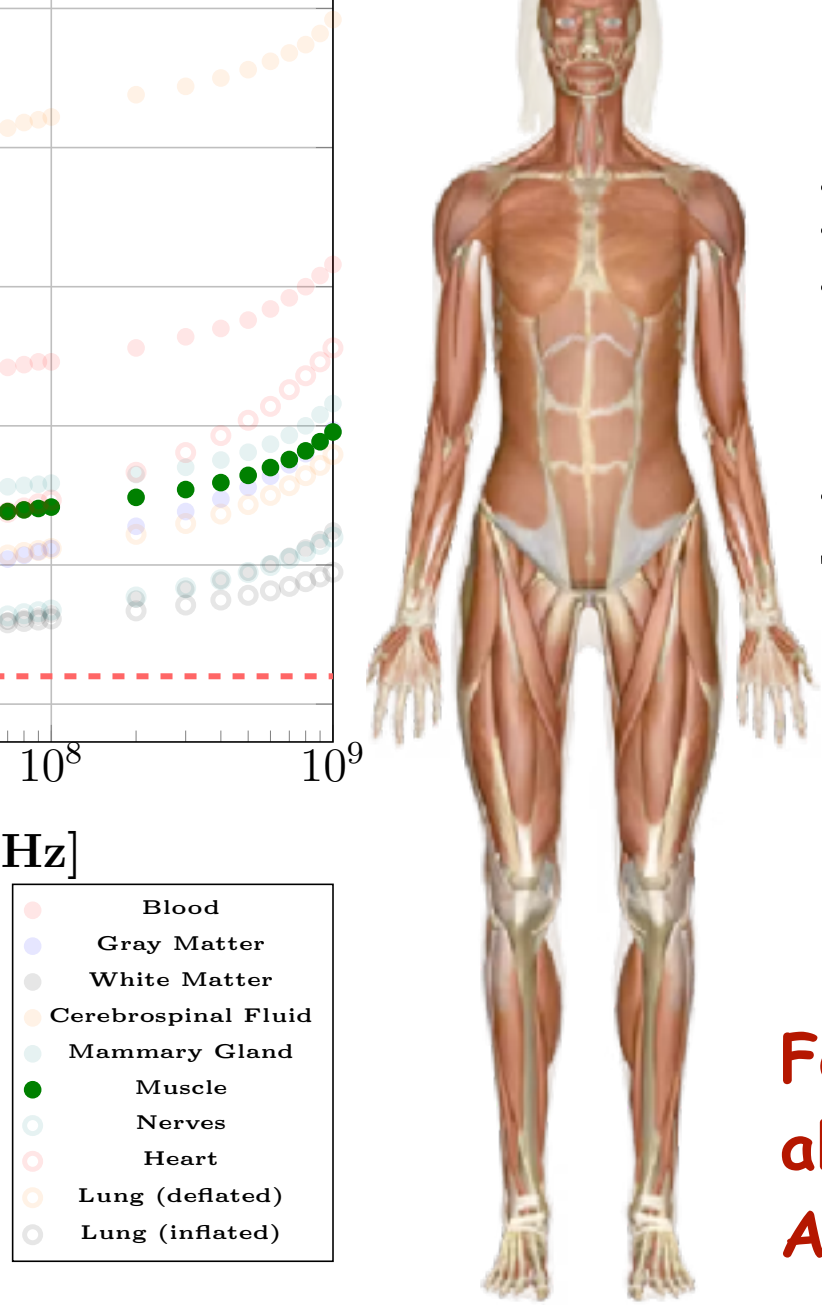


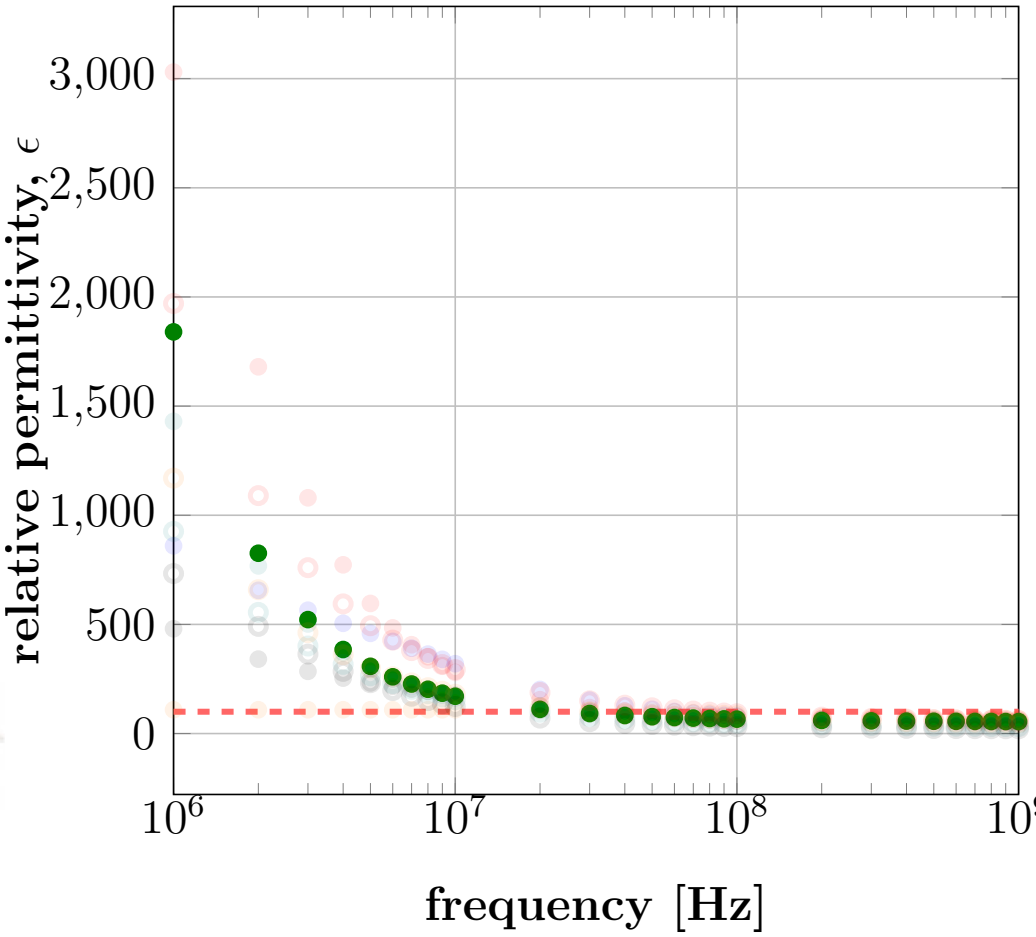


Most Medical Diagnostic Technology have problems penetrating Bones

GLOphotonics



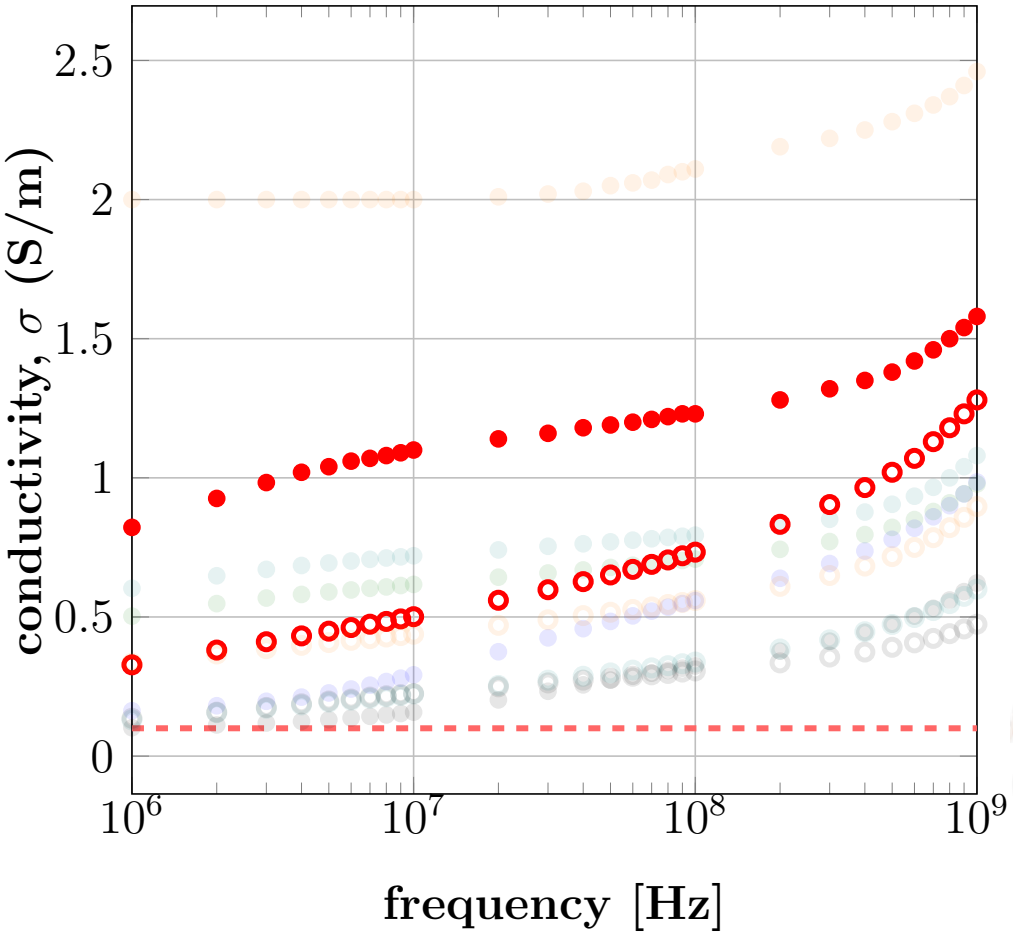


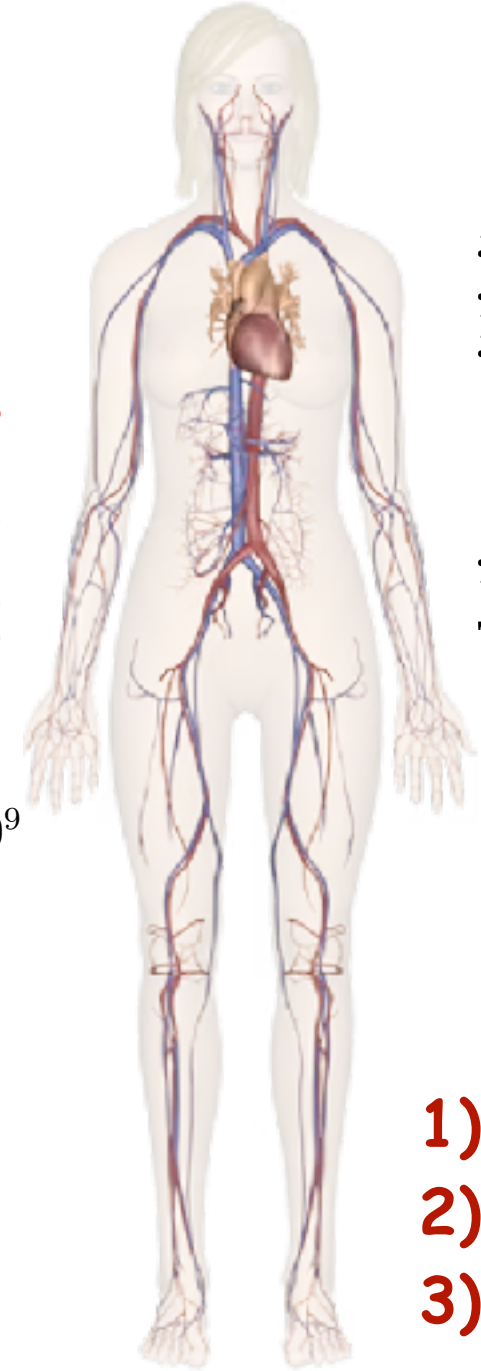


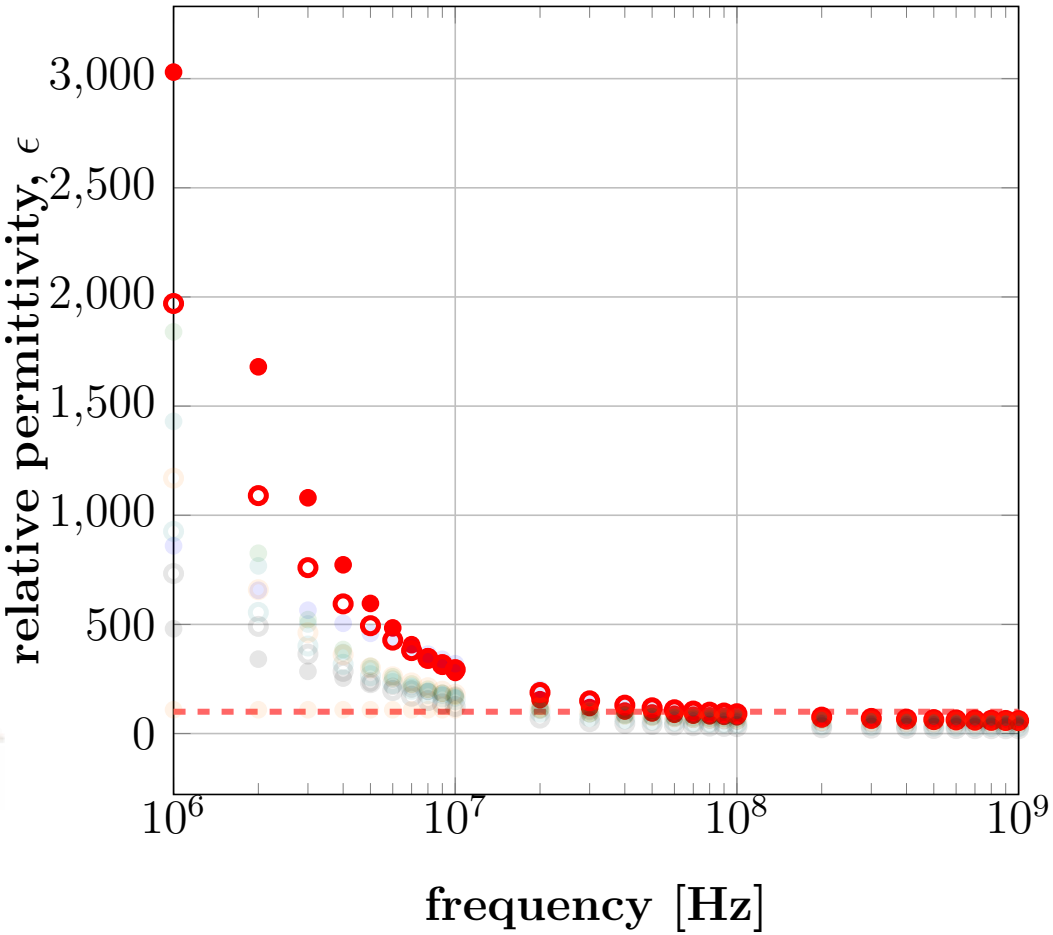
Blood
Gray Matter
White Matter
Cerebrospinal Fluid
Mammary Gland
Muscle
Nerves
Heart
Lung (deflated)
Lung (inflated)

GLOphotonics

Following Neuro-Muscular Problems along the chain from Neural Activity to Muscular Motion !!!

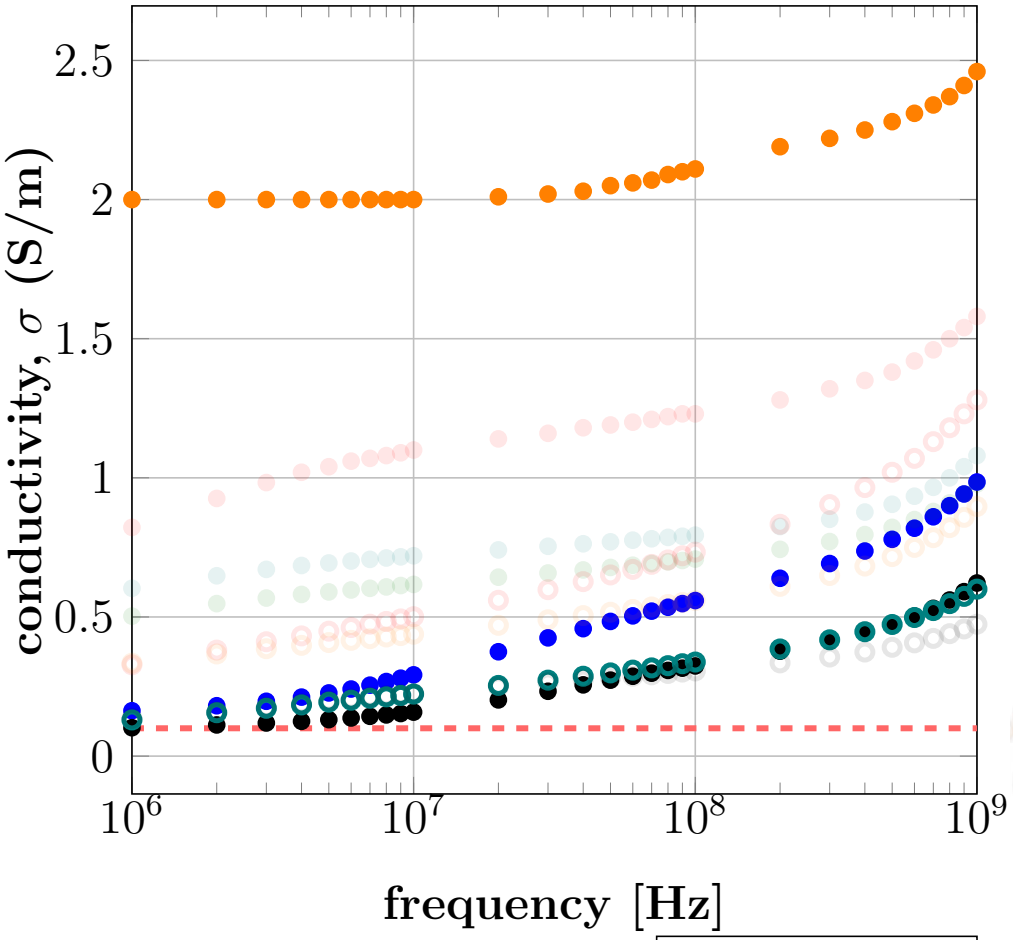


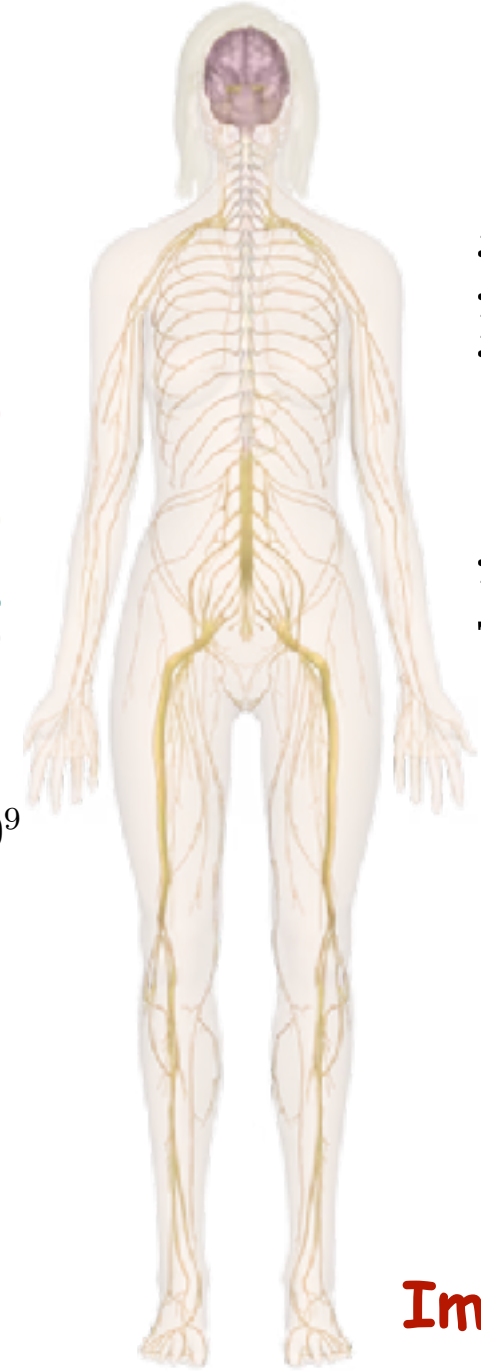


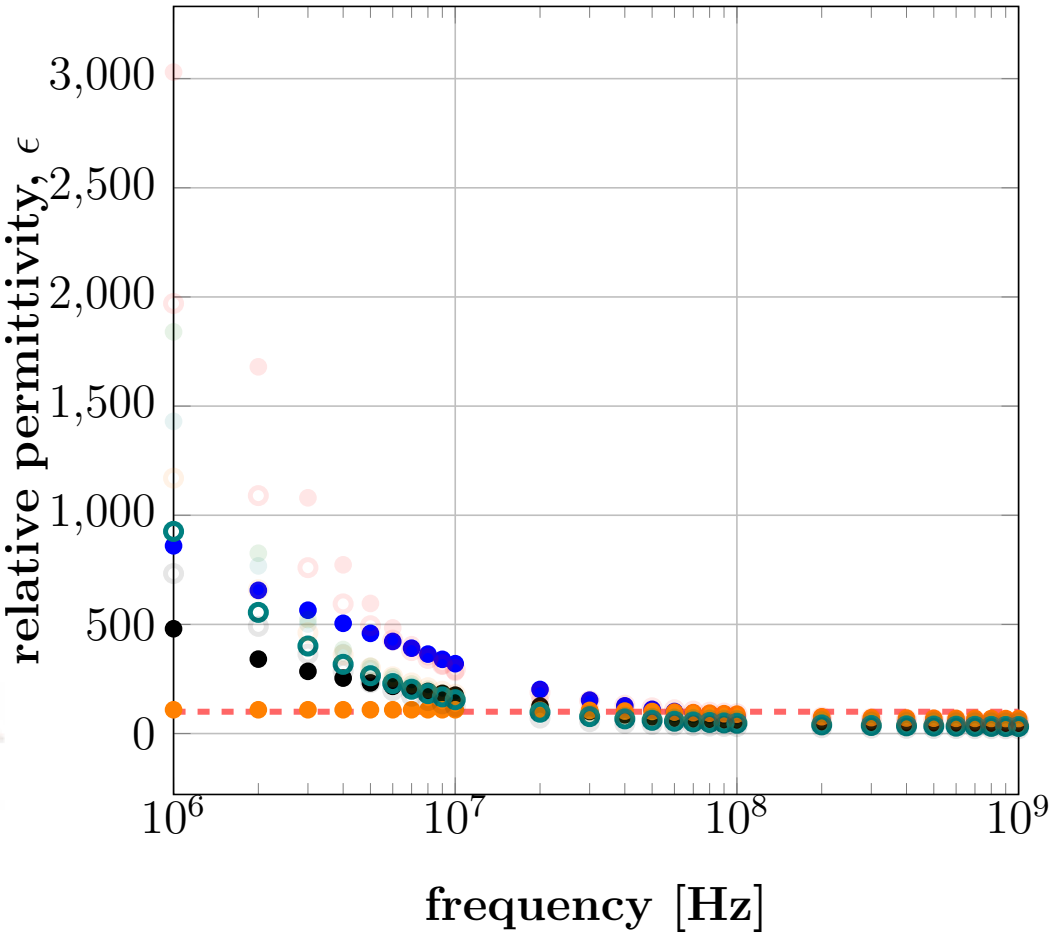


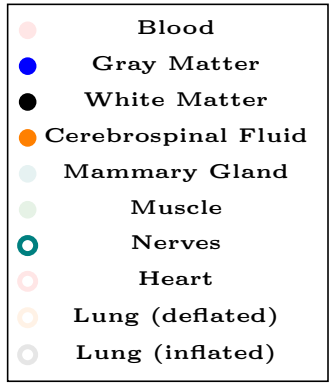
1) Cardiac Fibrillation Prediction !!!
2) Pre-Natal HeartBeats !!!
3) Personal ID via 'HeartPrints' !!!

GLOphotonics









GLOphotonics

Important in an Aging Population !!!

HOLLOW CORE PHOTONICS
CRYSTAL FIBER & PHOTONIC MICROCELL™

BEAM DELIVERY

PULSE COMPRESSION

FREQUENCY
CONVERSION & LASERS

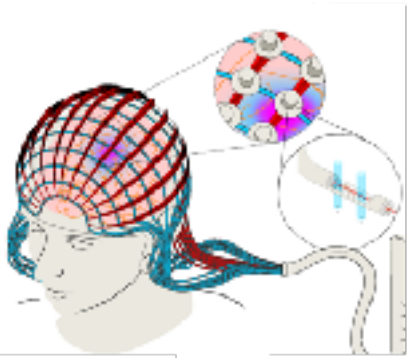
Quantum tech

LOW LATENCY DATACOM

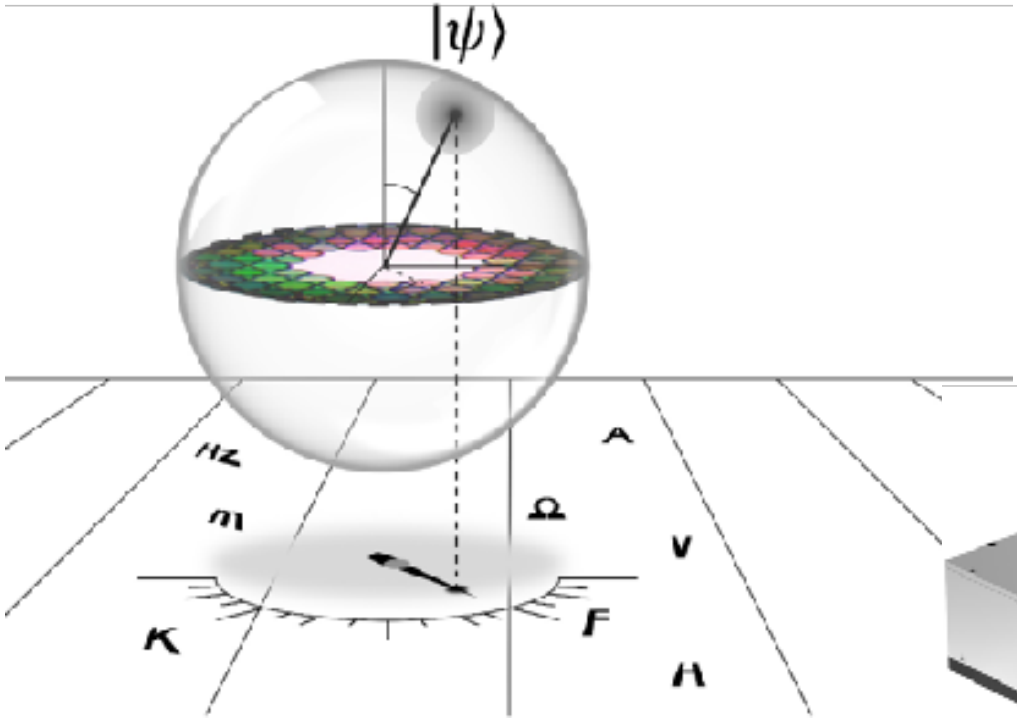
TECHNOLOGY SOLUTIONS

Merci Beaucoup
Thank You

Miniature atomic clocks & frequency reference



Magnometery & brain imaging solutions



Quantum photon sources & memories

*

GLOphotonics

HOLLOW CORE PHOTONICS
CRYSTAL FIBER & PHOTONIC MICROCELL™

BEAM DELIVERY

PULSE COMPRESSION

FREQUENCY
CONVERSION & LASERS

Quantum tech

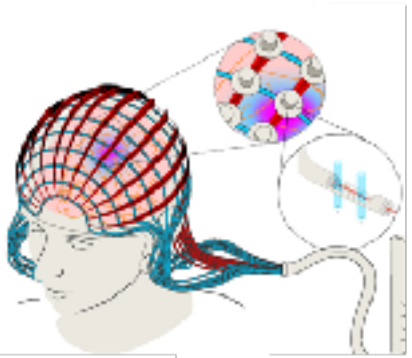
LOW LATENCY DATACOM

TECHNOLOGY SOLUTIONS

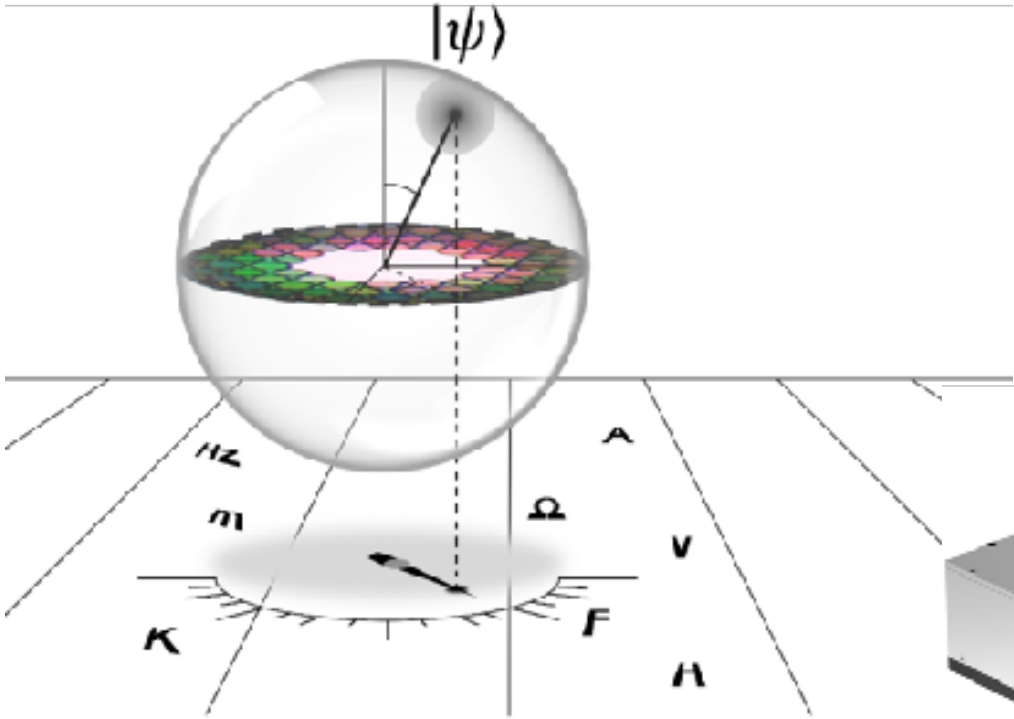
Product family and product development

BTU-QuTech

Miniature atomic clocks & frequency reference



Magnometery & brain imaging solutions



Quantum photon sources & memories

*

GLOphotonics

HOLLOW CORE PHOTONICS
CRYSTAL FIBER & PHOTONIC MICROCELL™

BEAM DELIVERY

PULSE COMPRESSION

FREQUENCY CONVERSION & LASERS

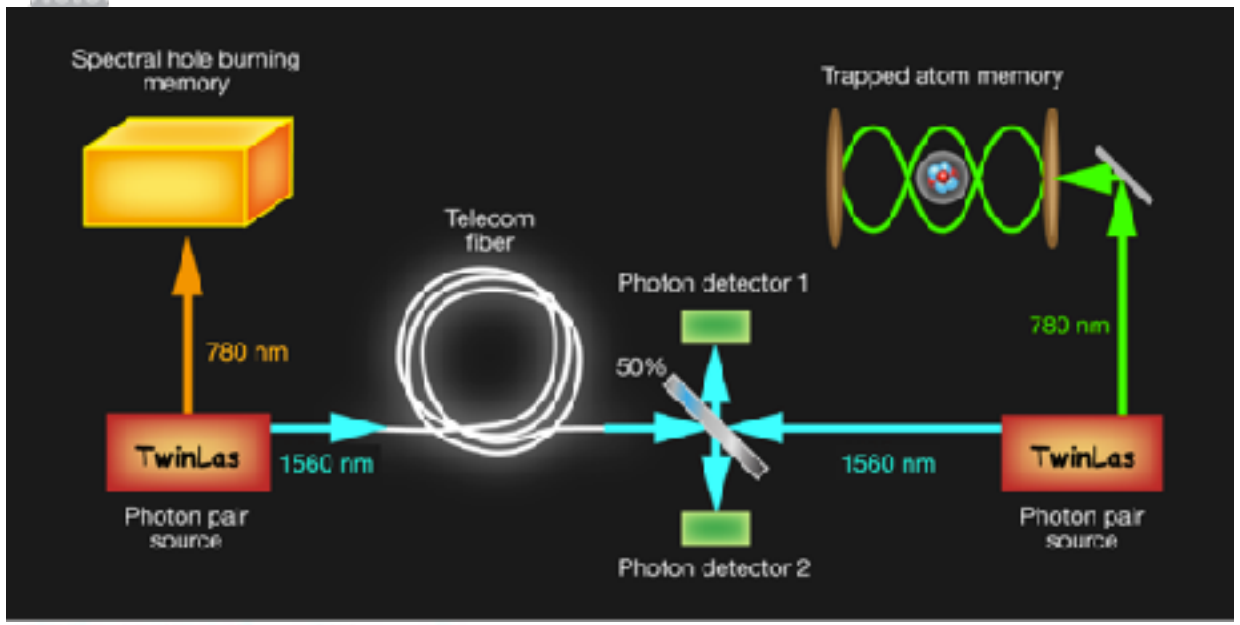
Quantum tech

Product family and product development

Examples of Qtech activities

Quantum sources Quantum sensors Quantum brain imaging system

1) Spans both the telecommunication and quantum memory band!
2) Modular, 'plug n play' design for networked quantum communication



Opens the door for truly global Quantum Internet of Things

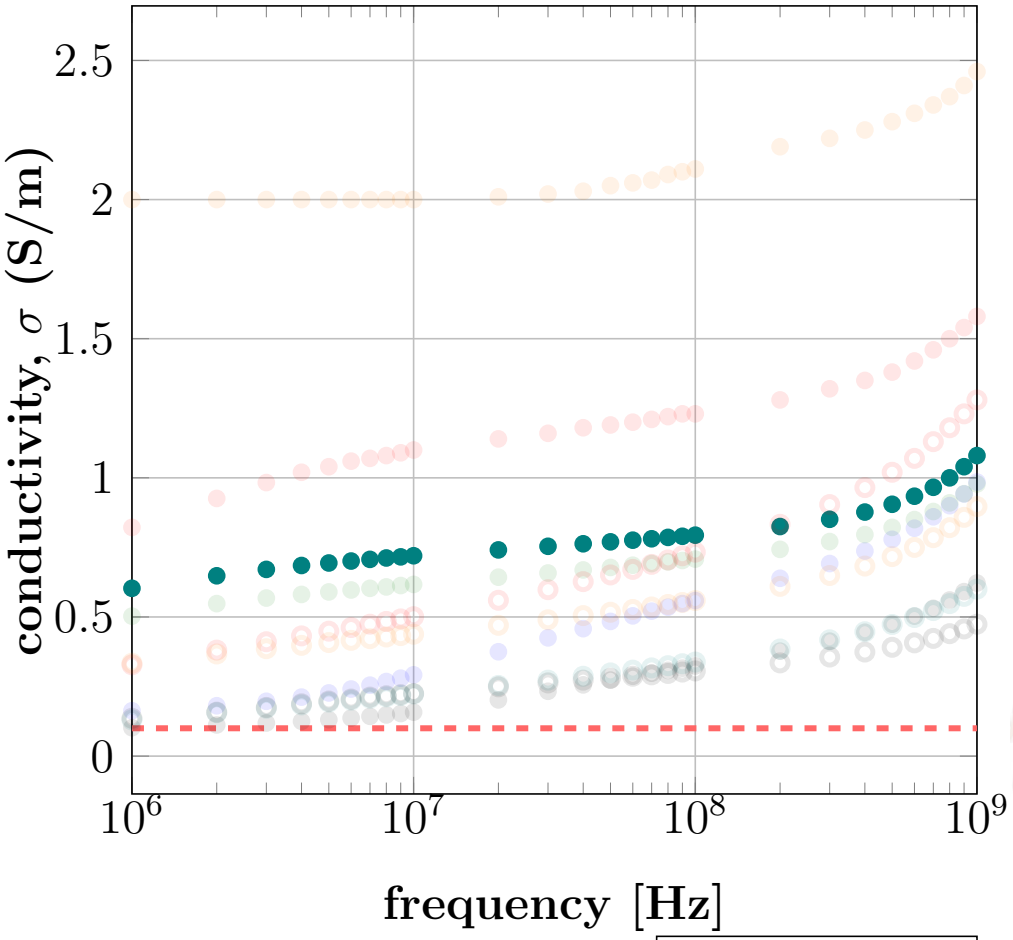
GLOphotonics

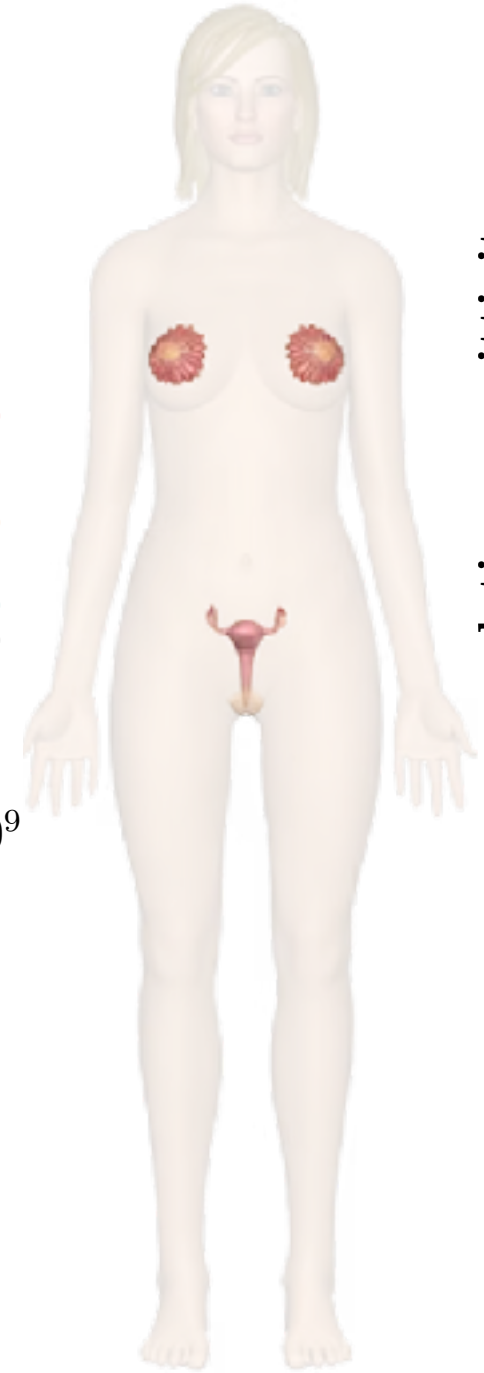
GLOphotonics

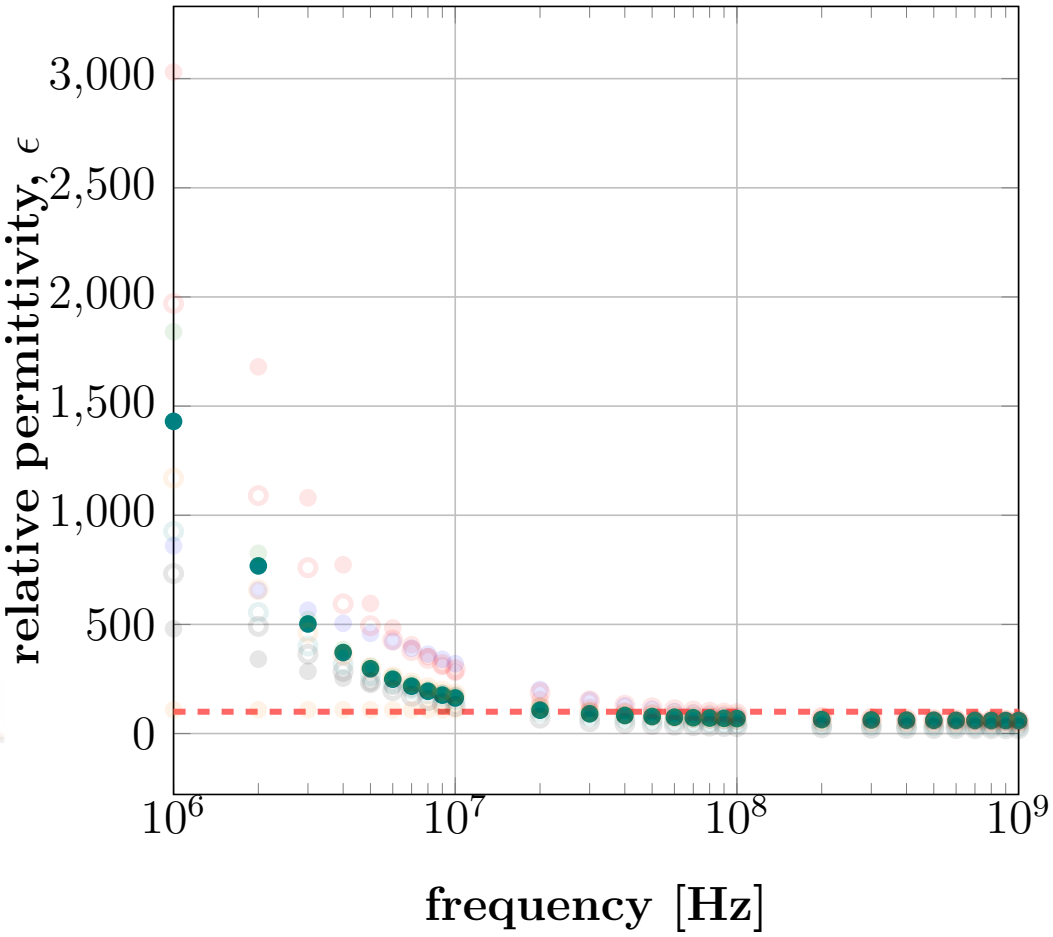
The Hollow-Core PCF & Photonic MicroCell™ company

Merci

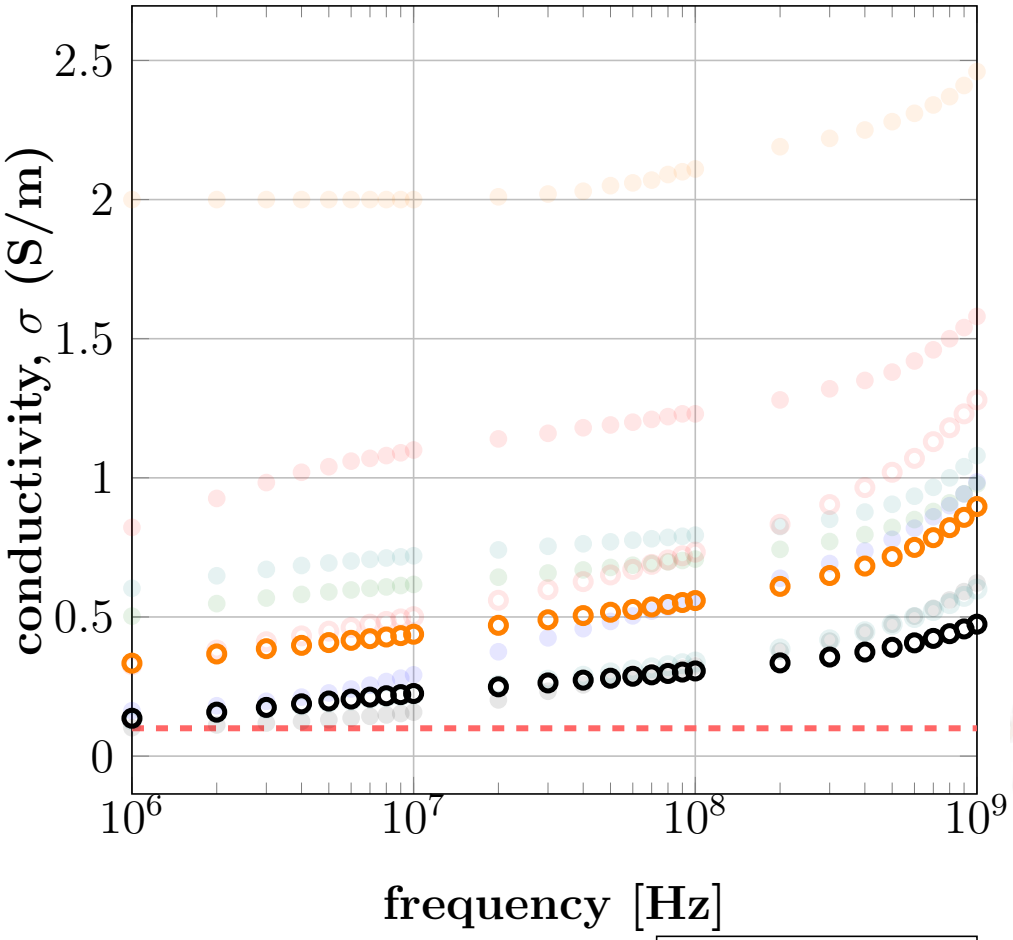
Thank you

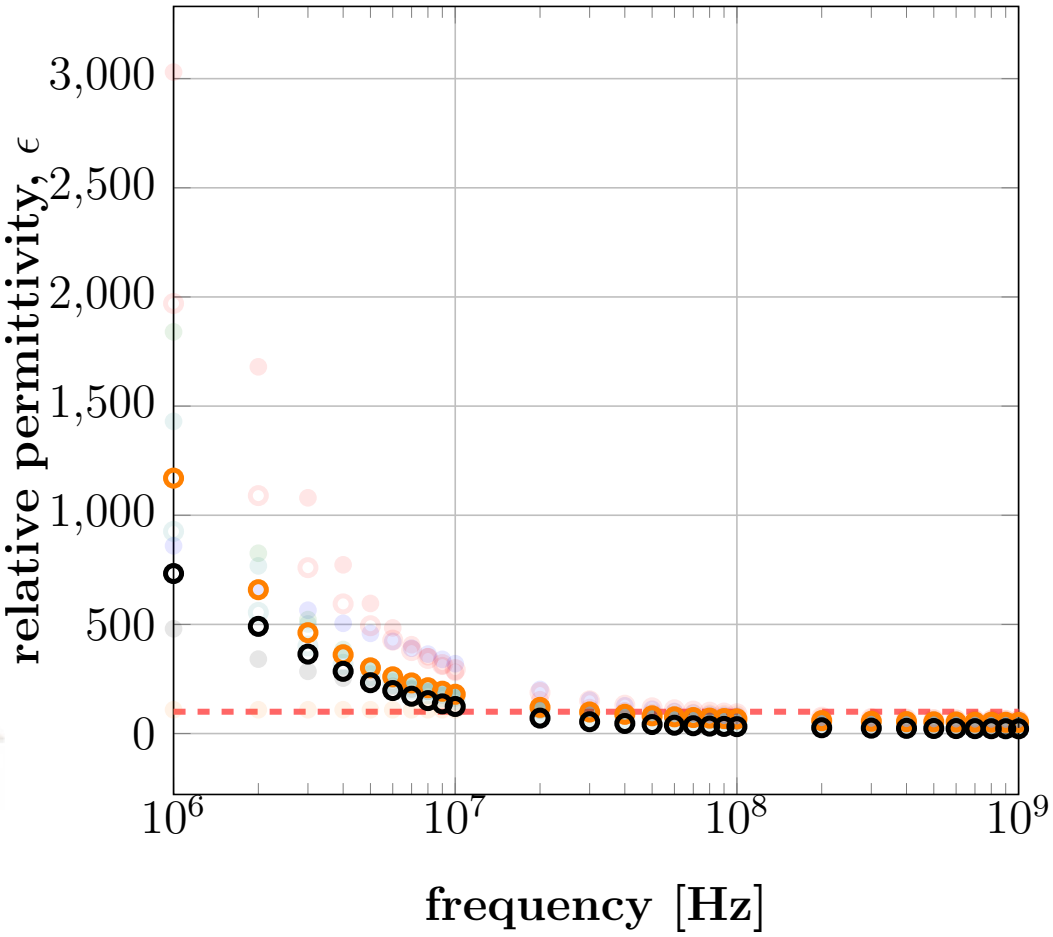






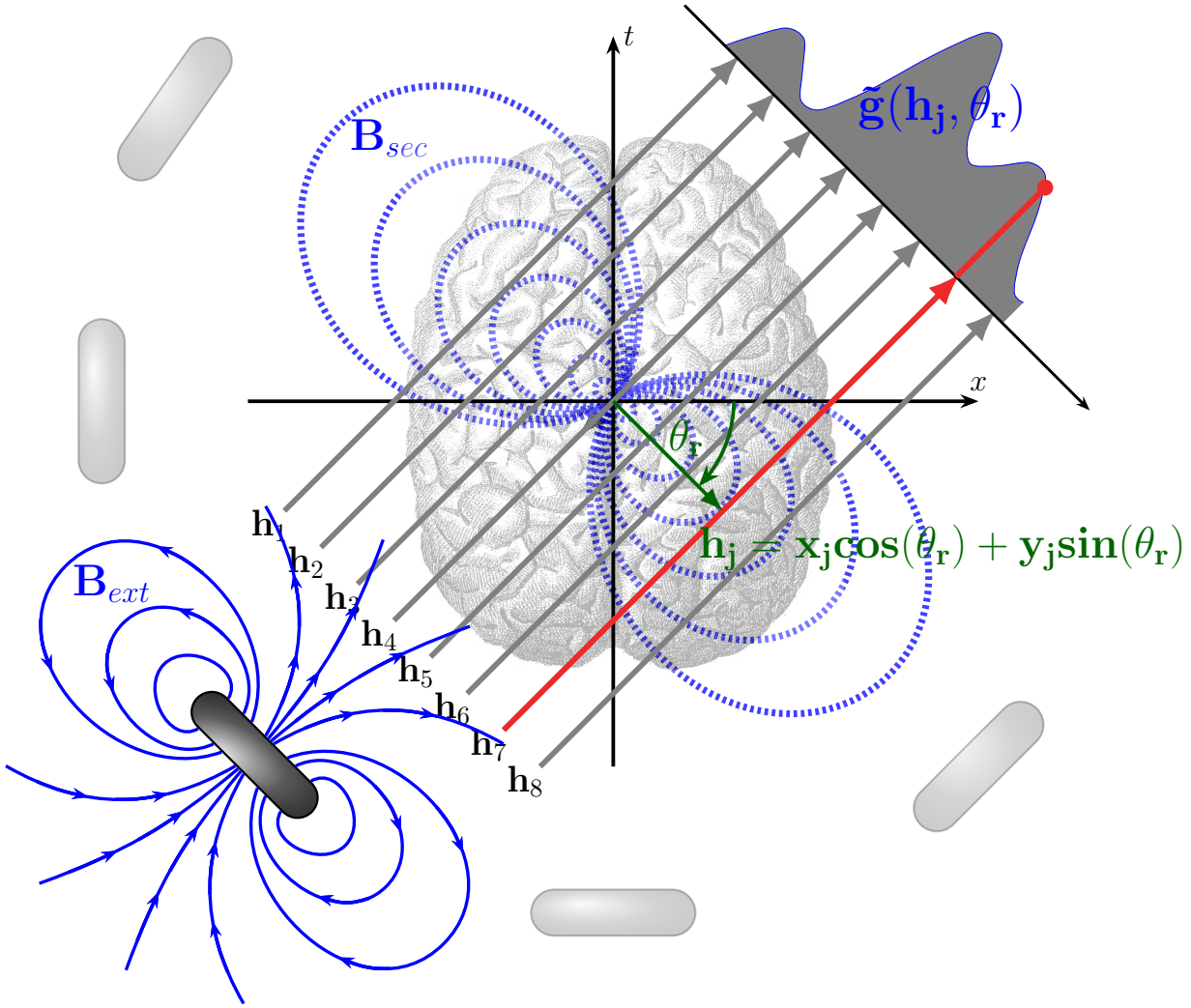
GLOphotonics





Blood
Gray Matter
White Matter
Cerebrospinal Fluid
Mammary Gland
Muscle
Nerves
Heart
Lung (deflated)
Lung (inflated)

GLOphotonics



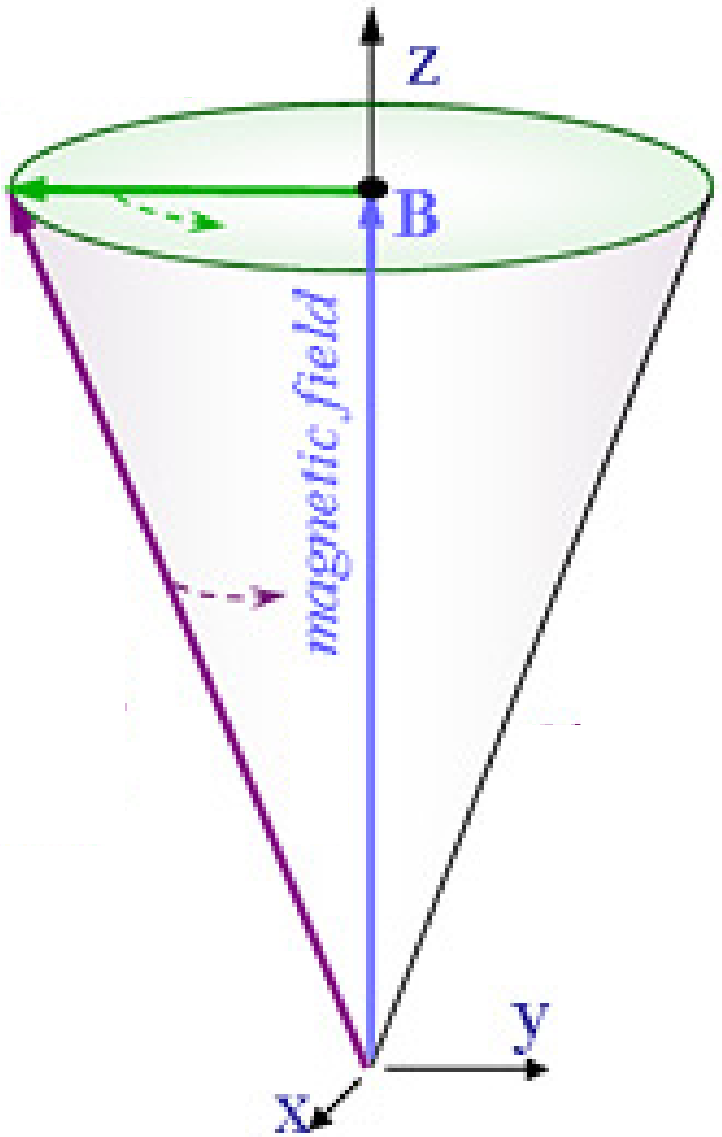
Three different dispersions regimes of conductivity:

1) Alpha dispersions (Hz-kHz) are associated with ionic diffusion processes at the cellular membrane level.
2) Beta dispersions (kHz-MHz) is caused by the polarization of cell membranes which acts as a barrier to ion flow and protein polarization.
3) Gamma dispersions (GHz) are associated with water polarization

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

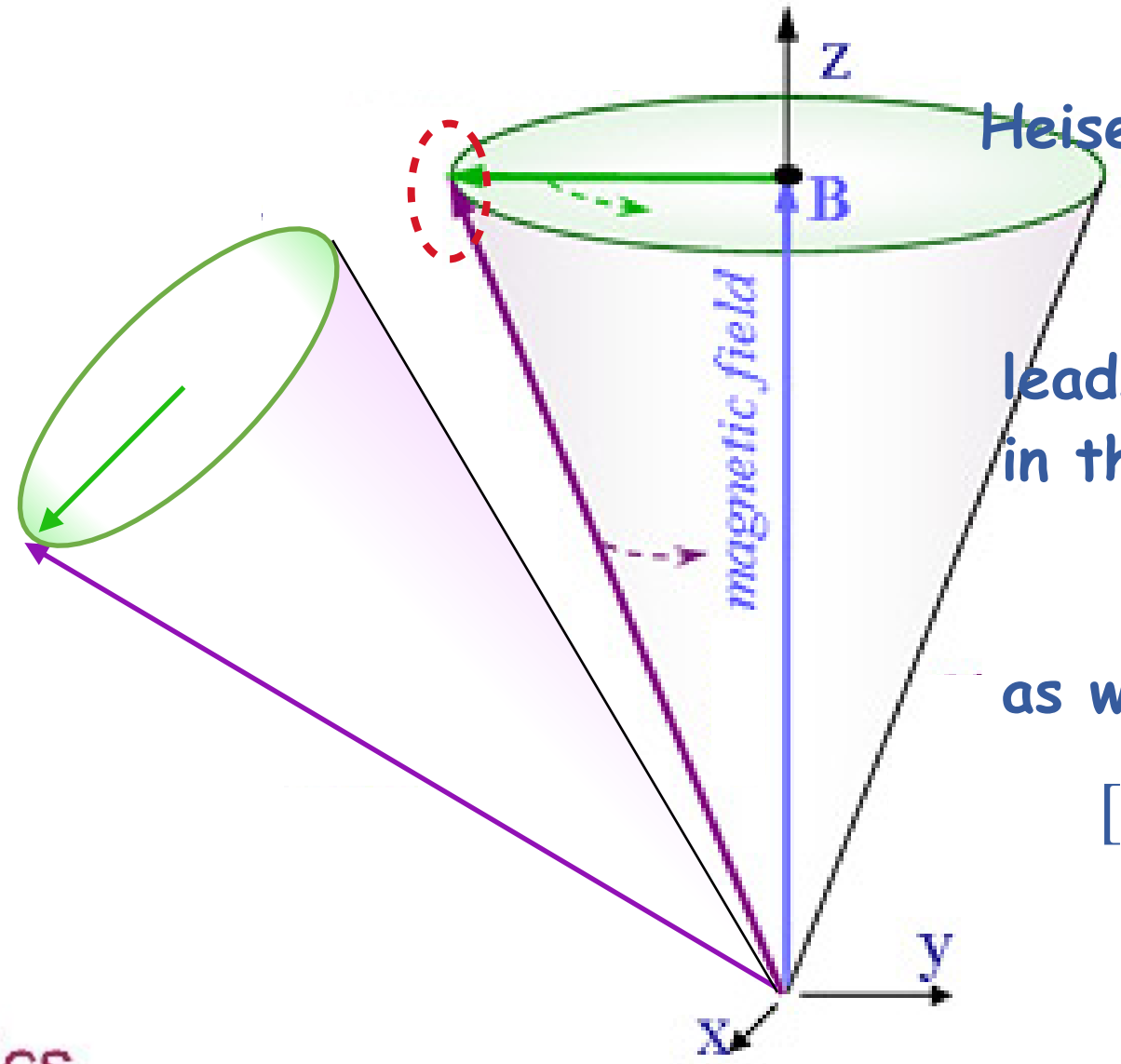
GLOphotonics

Intro Spin Squeezing



GLOphotonics

Measurement along one direction randomly disturbs orthogonal states



Heisenberg Uncertainty

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

leads to an intrinsic uncertainty in the instantaneous spin

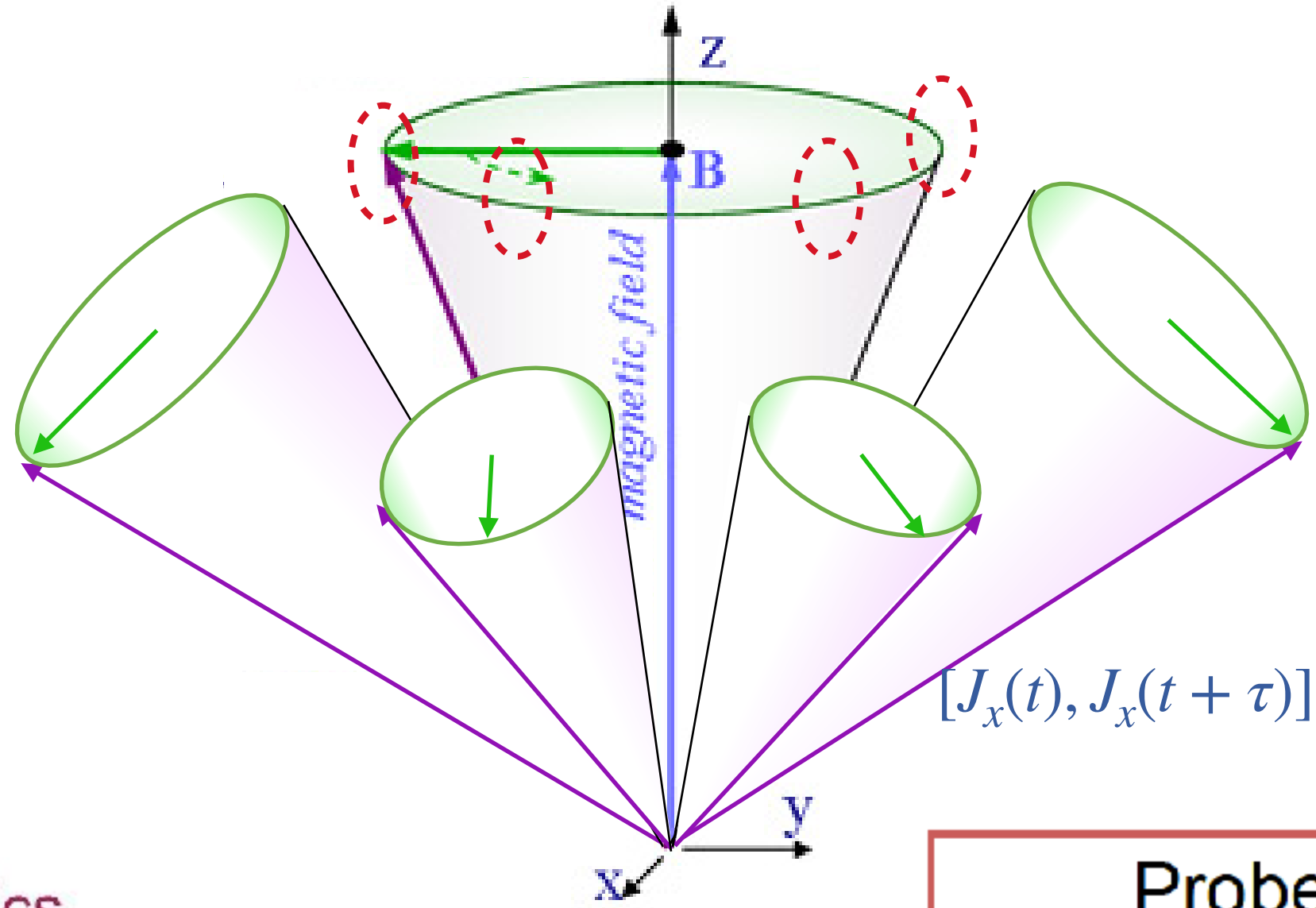
$$\delta J_x \delta J_y \geq J_z/2$$

as well as in time

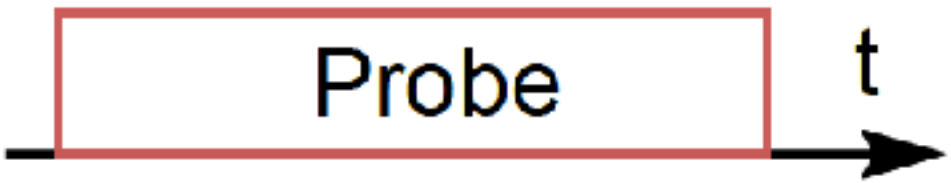
$$[J_x(t), J_x(t+\tau)] = iJ_z sin(\omega\tau)$$

GLOphotonics

leading to random, uncontrollable spin noise

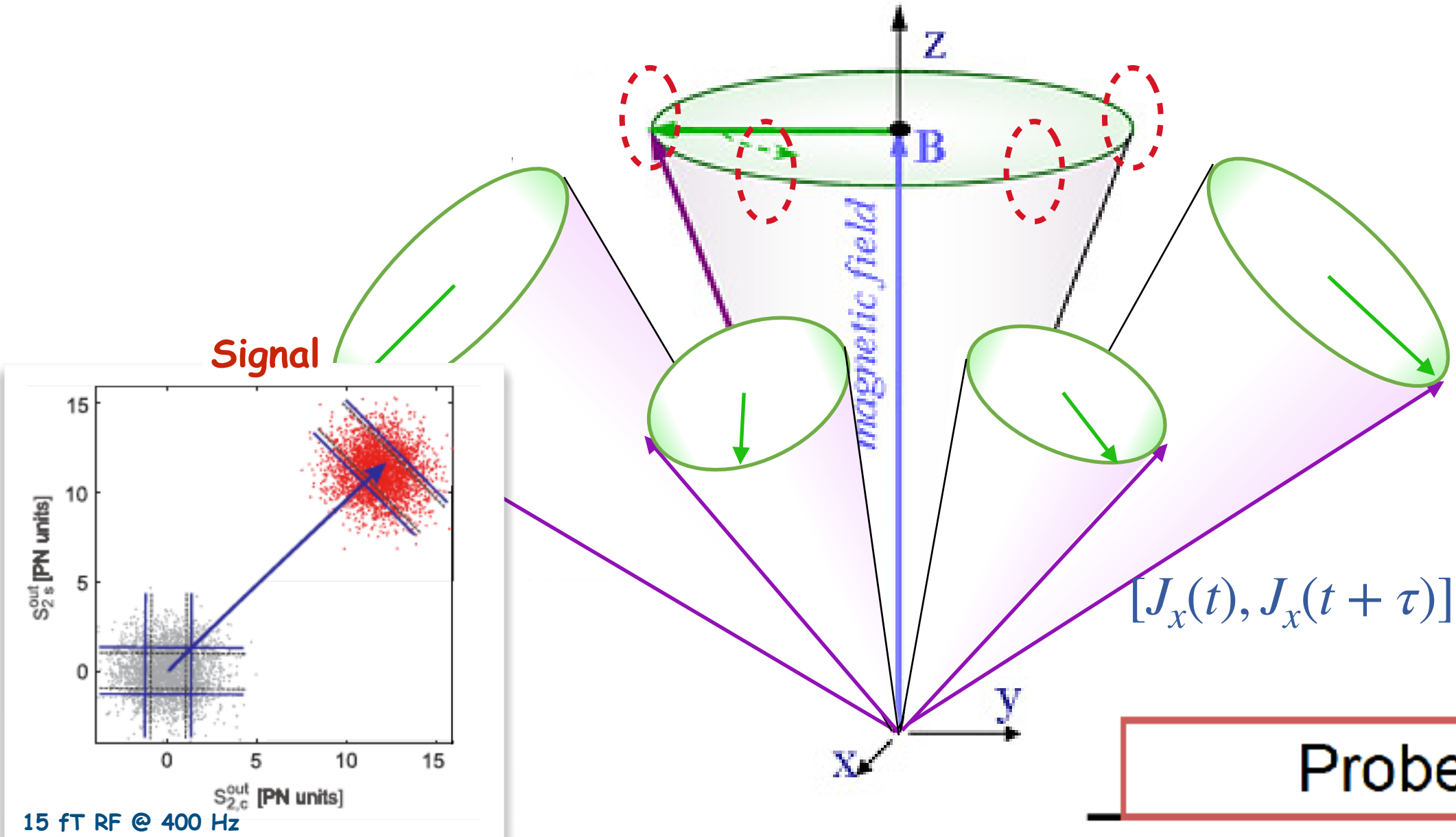


$$[J_x(t), J_x(t+\tau)] = iJ_z sin(\omega\tau)$$



GLOphotonics

Creates large circle of uncertainty → Heisenberg Uncertainty Principle

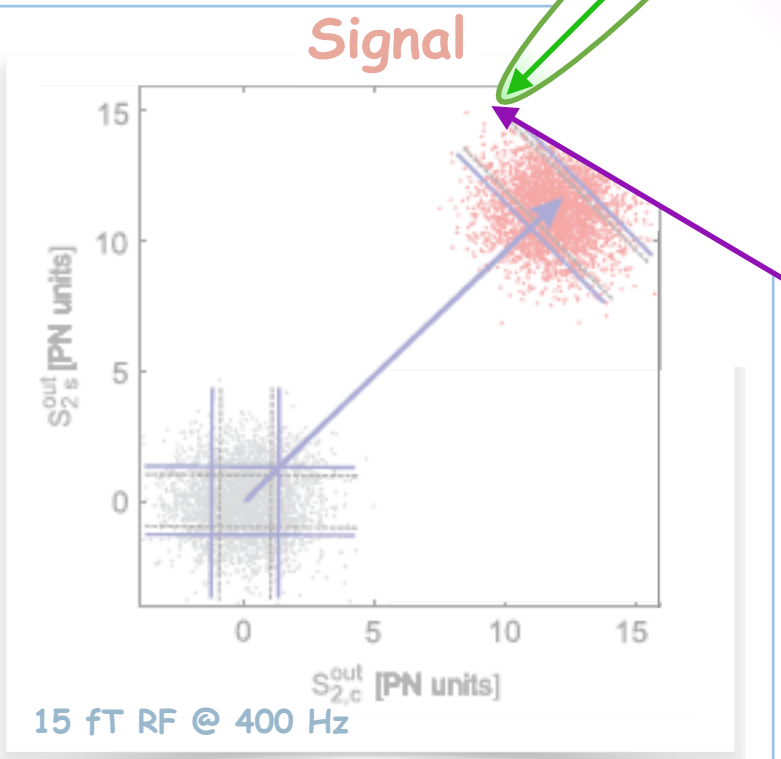


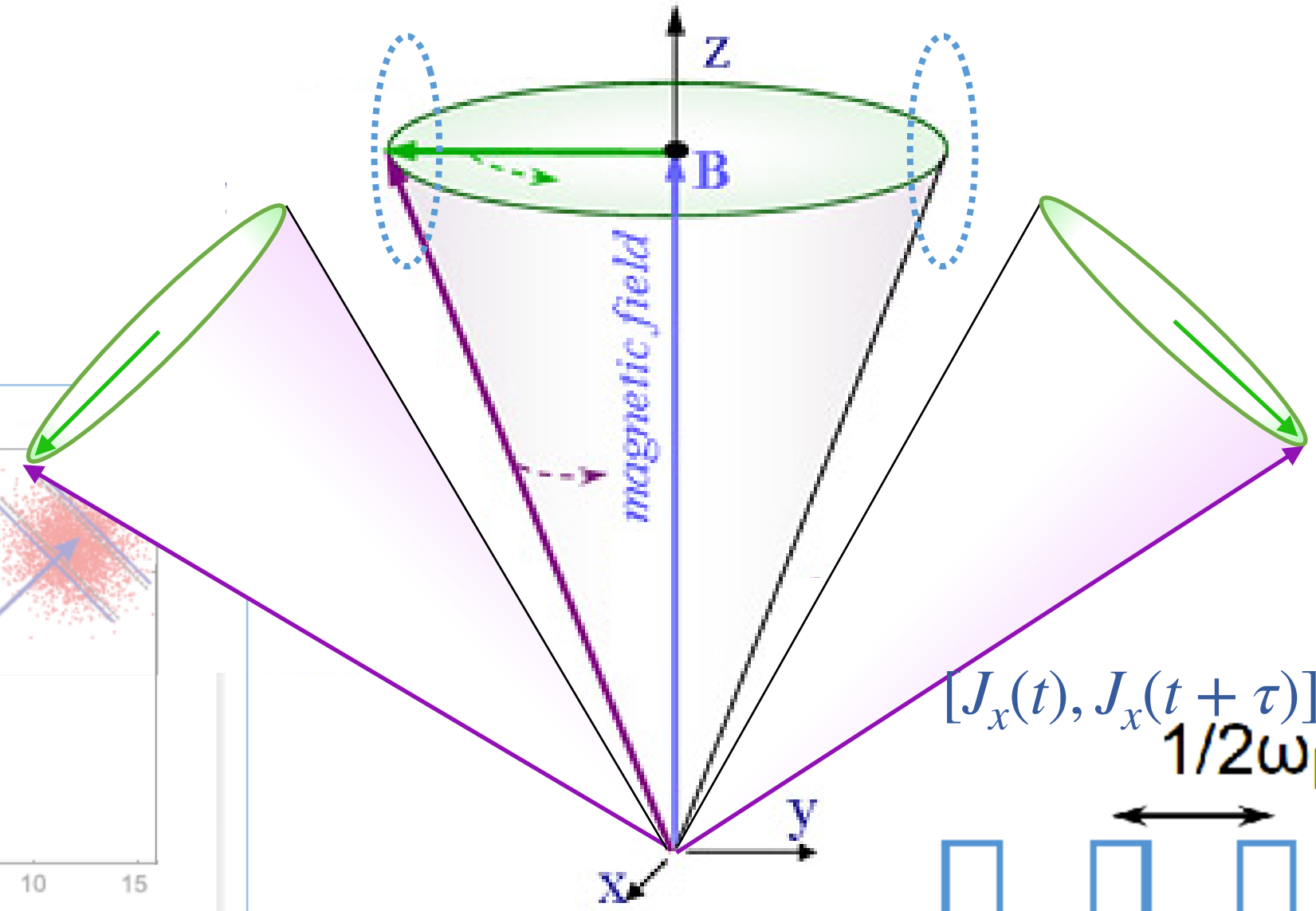
$$[J_x(t), J_x(t+\tau)] = iJ_z sin(\omega\tau)$$

Signal

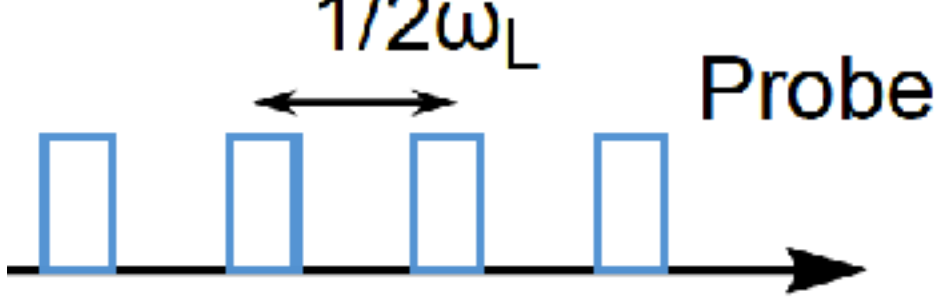
15 fT RF @ 400 Hz

Stroboscopic measurements at twice the frequency leads to disturbance only in one direction, allowing beyond Standard Quantum Limit Precision

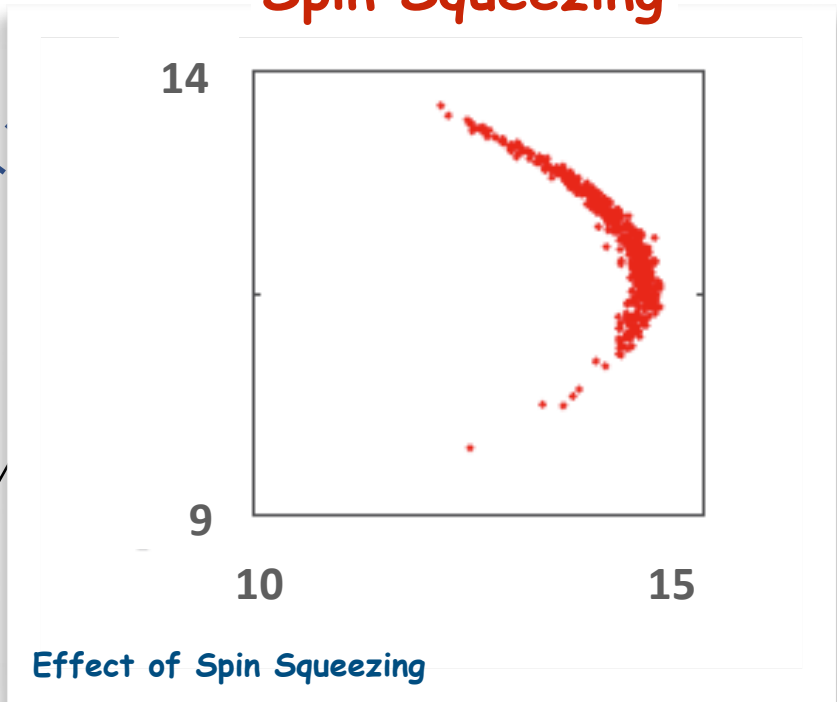




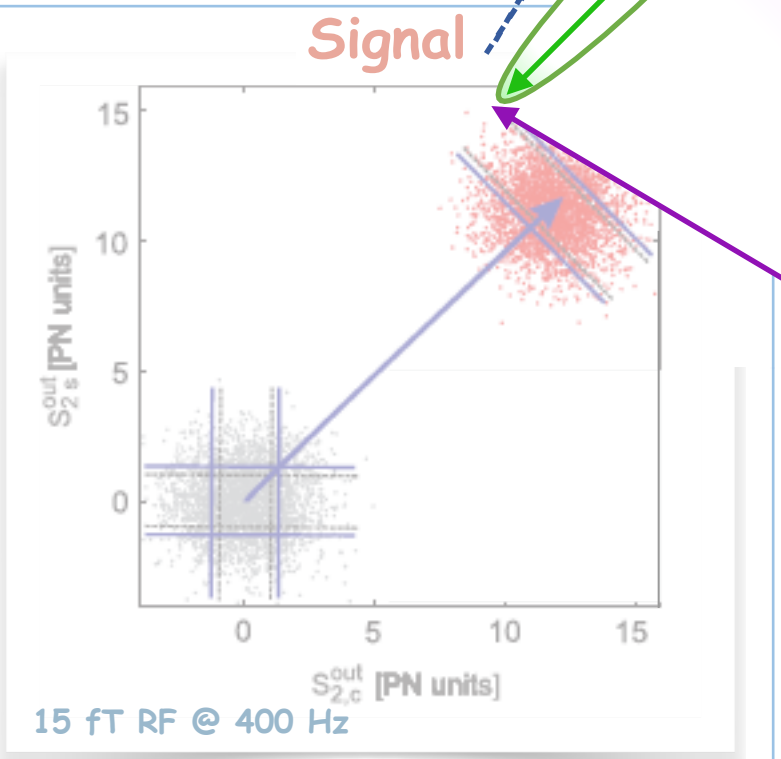
$$[J_x(t), J_x(t+\tau)] = iJ_z sin(\omega\tau)$$

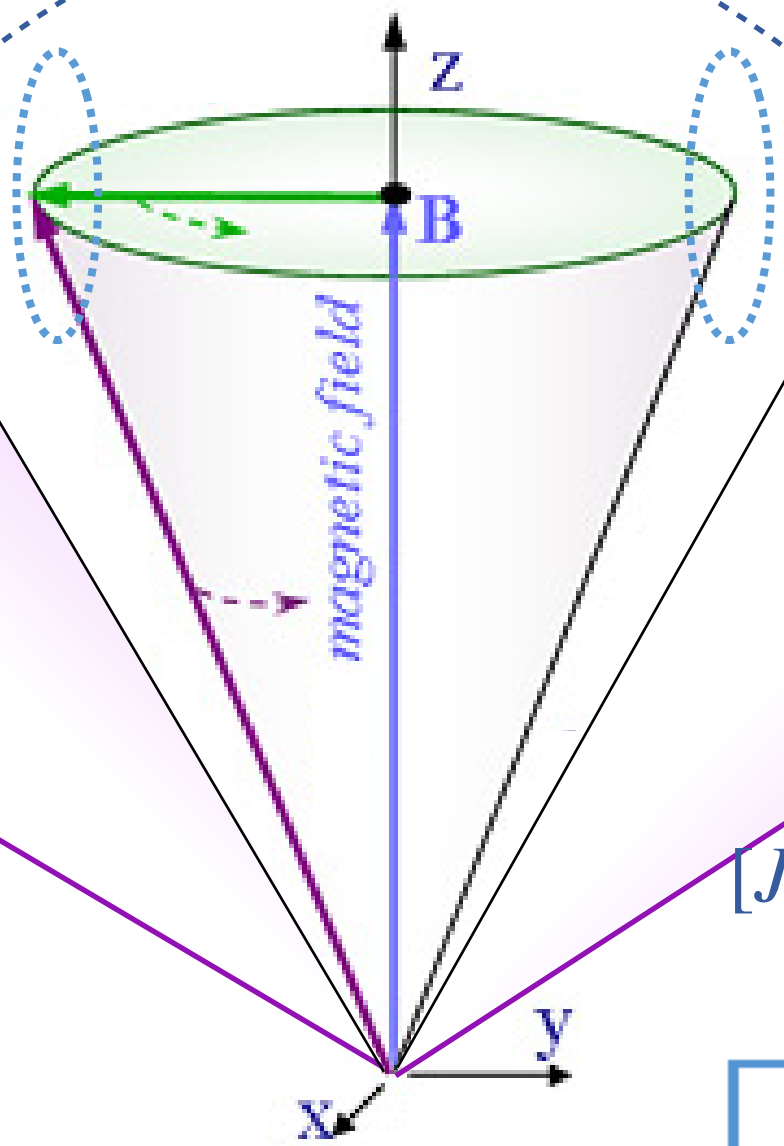


Spin Squeezing

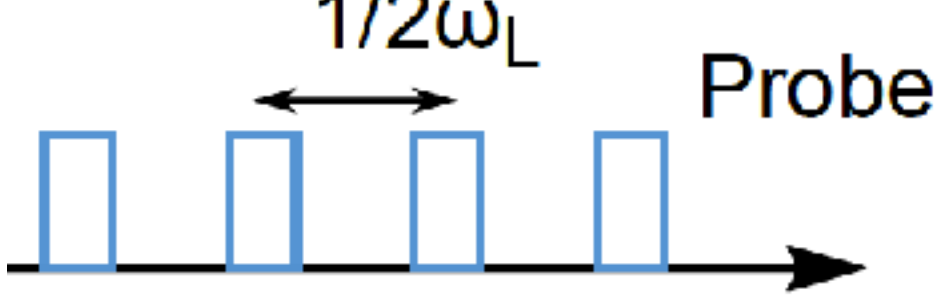


Effect of Spin Squeezing





$$[J_x(t), J_x(t+\tau)] = iJ_z sin(\omega\tau)$$



HOLLOW CORE PHOTONICS
CRYSTAL FIBER & PHOTONIC MICROCELL™

BEAM DELIVERY

PULSE COMPRESSION

FREQUENCY
CONVERSION & LASERS

Quantum tech

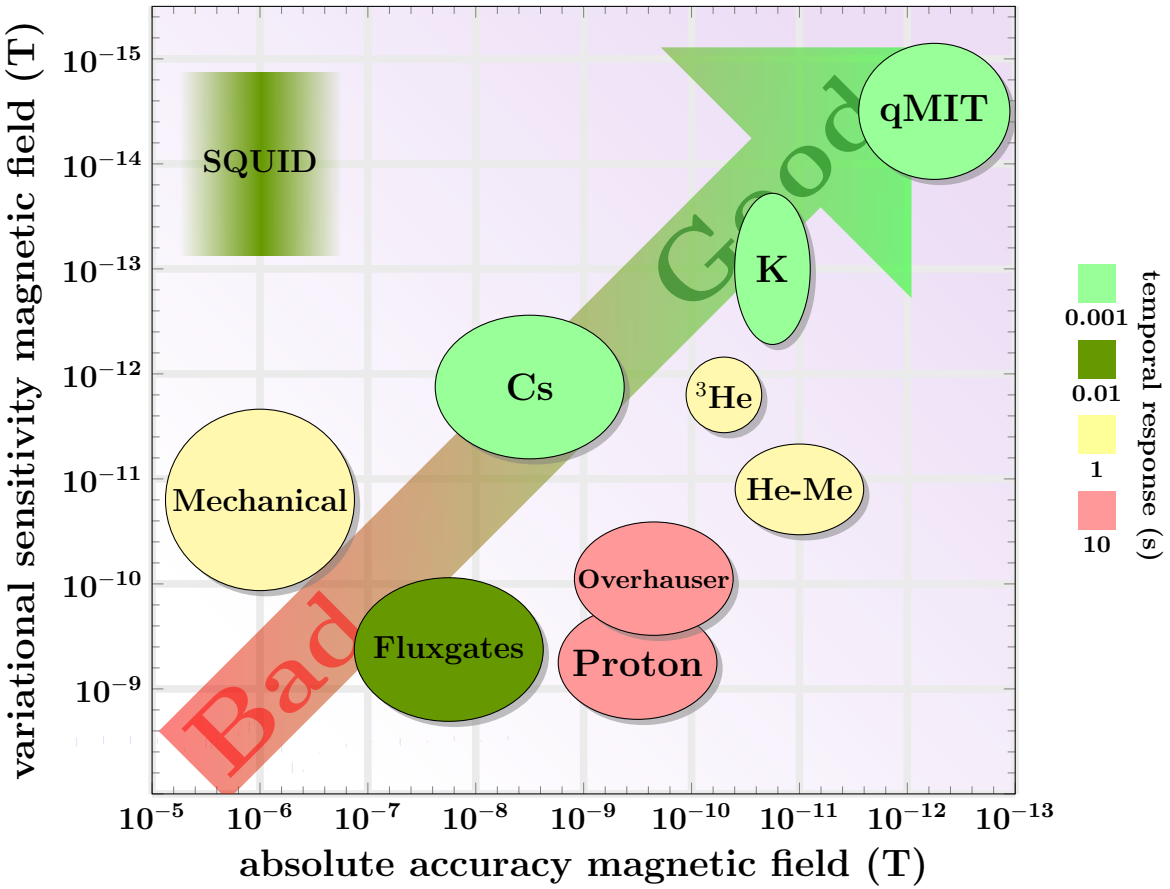
LOW LATENCY DATACOM

TECHNOLOGY SOLUTIONS

Product family and product development

Examples of Qtech activities

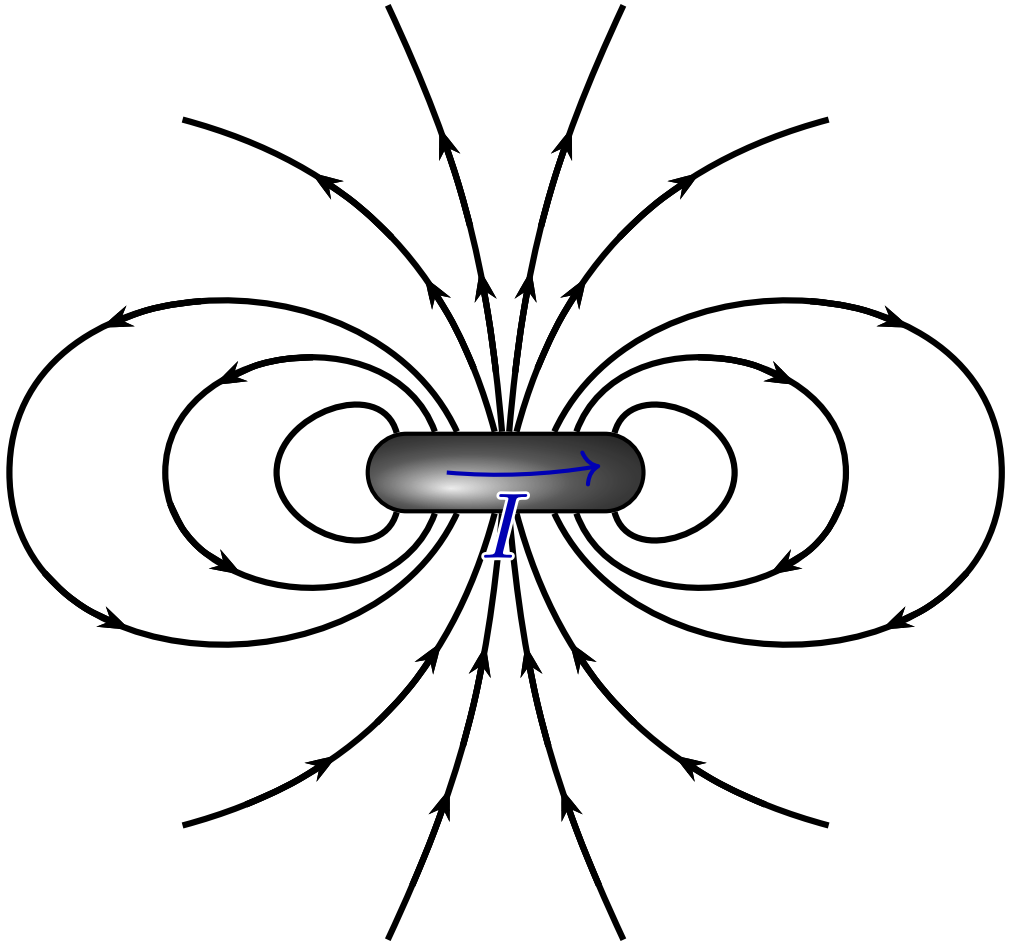
Quantum sources | **Quantum sensors** | Quantum brain imaging system



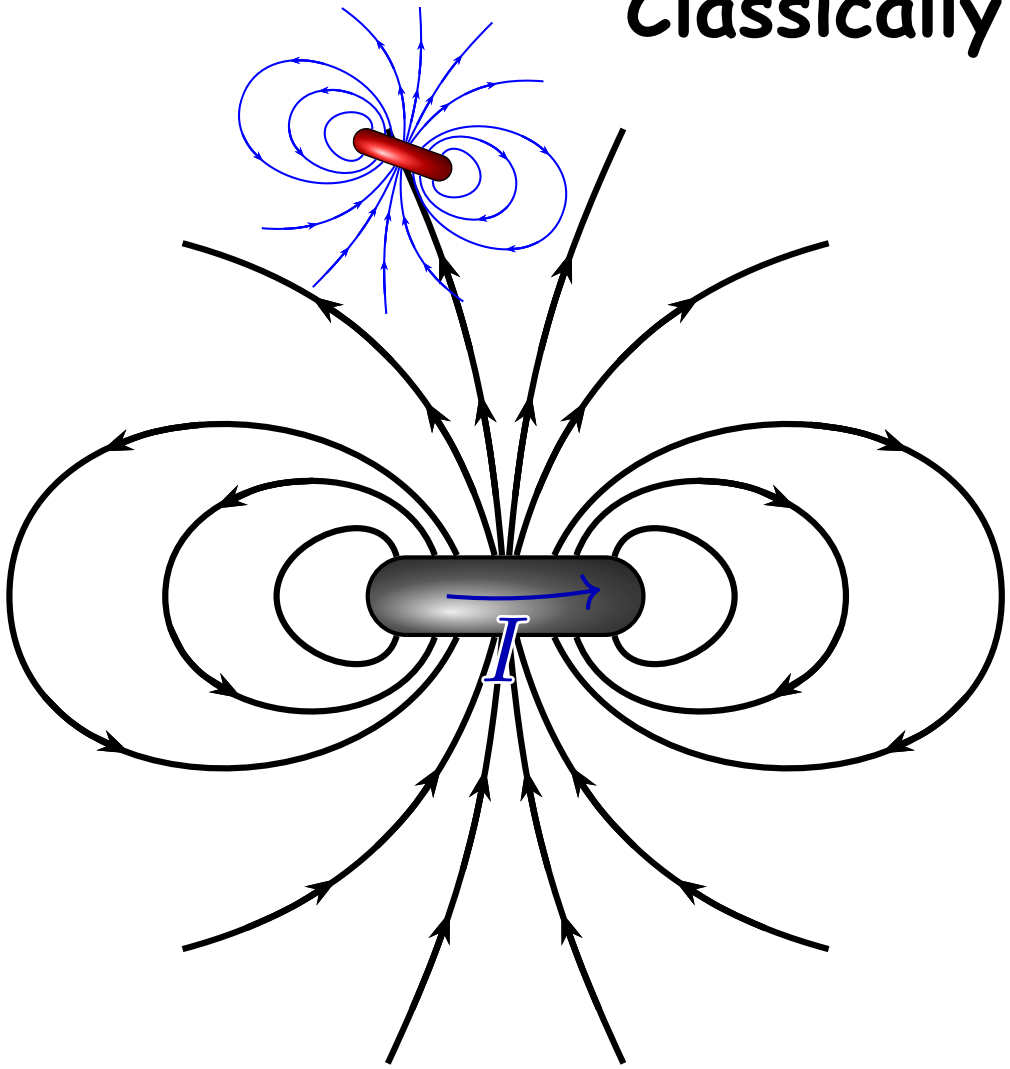
*

GLOphotonics

Classically Non-Describable Two Valuedness

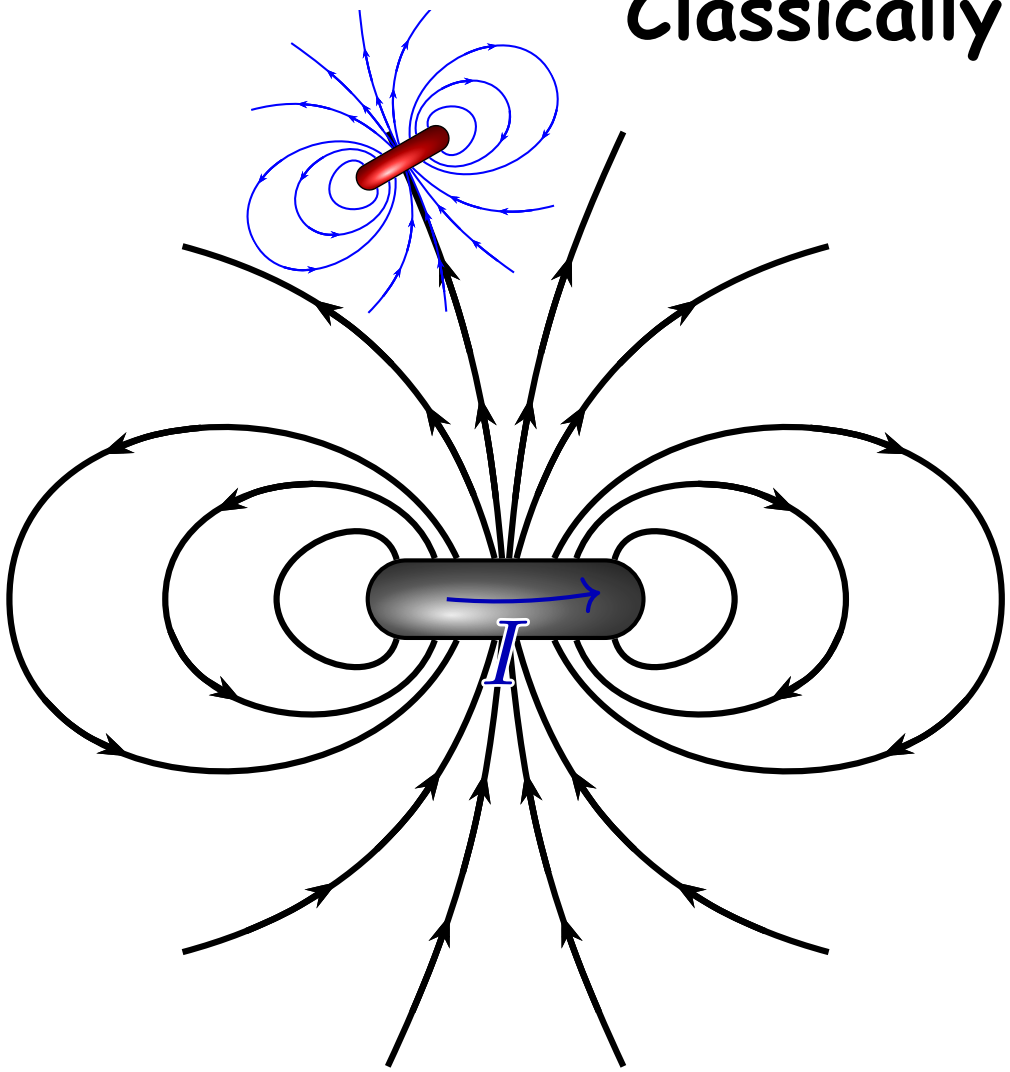


Classically Non-Describable Two Valuedness

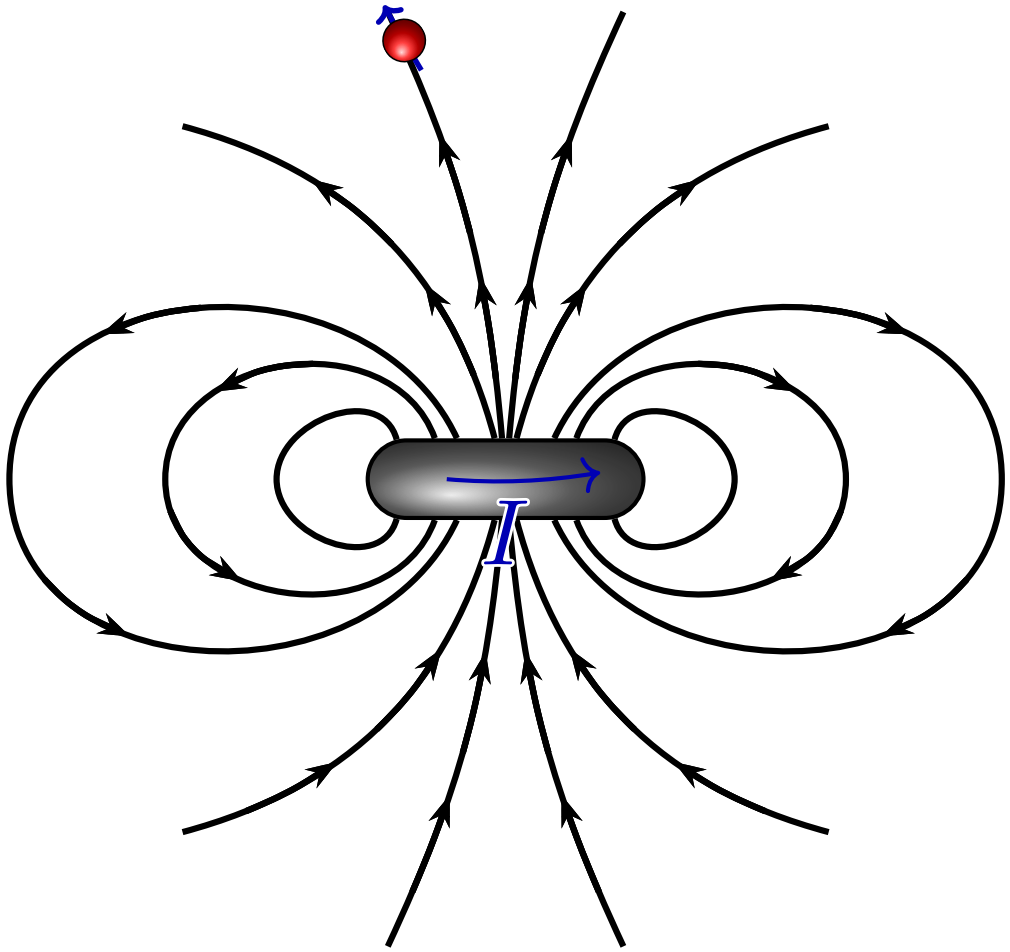


GLOphotonics

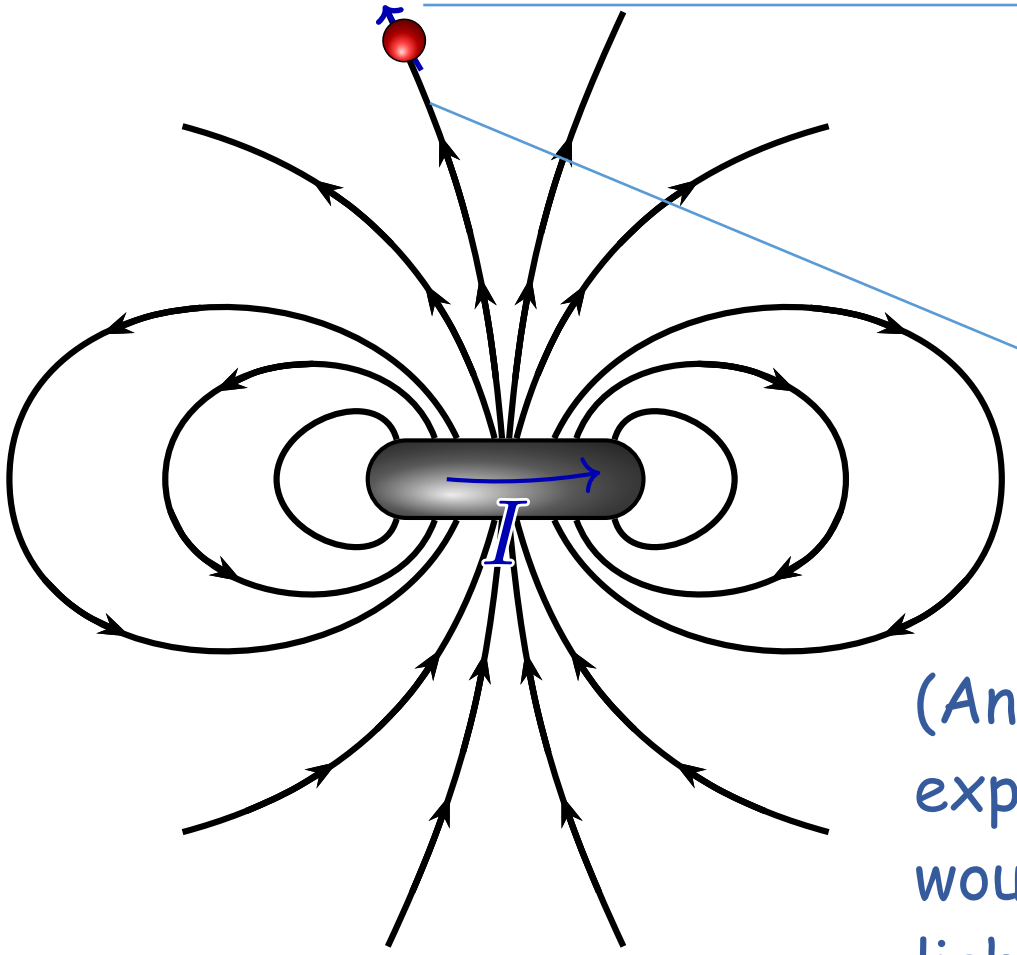
Classically Non-Describable Two Valuedness

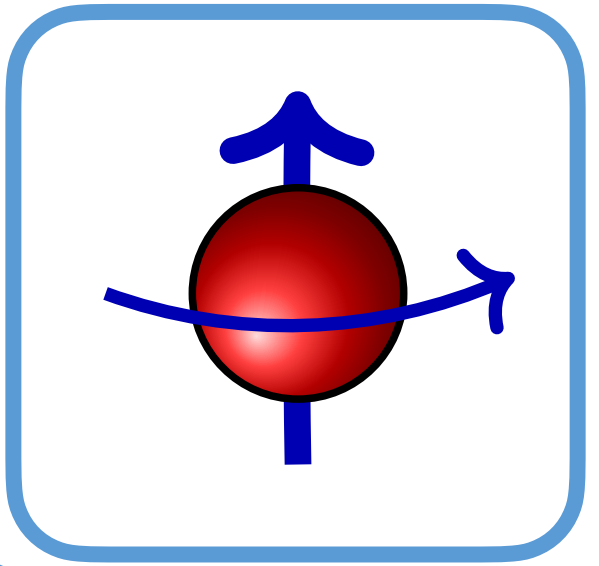


Classically Non-Describable Two Valuedness



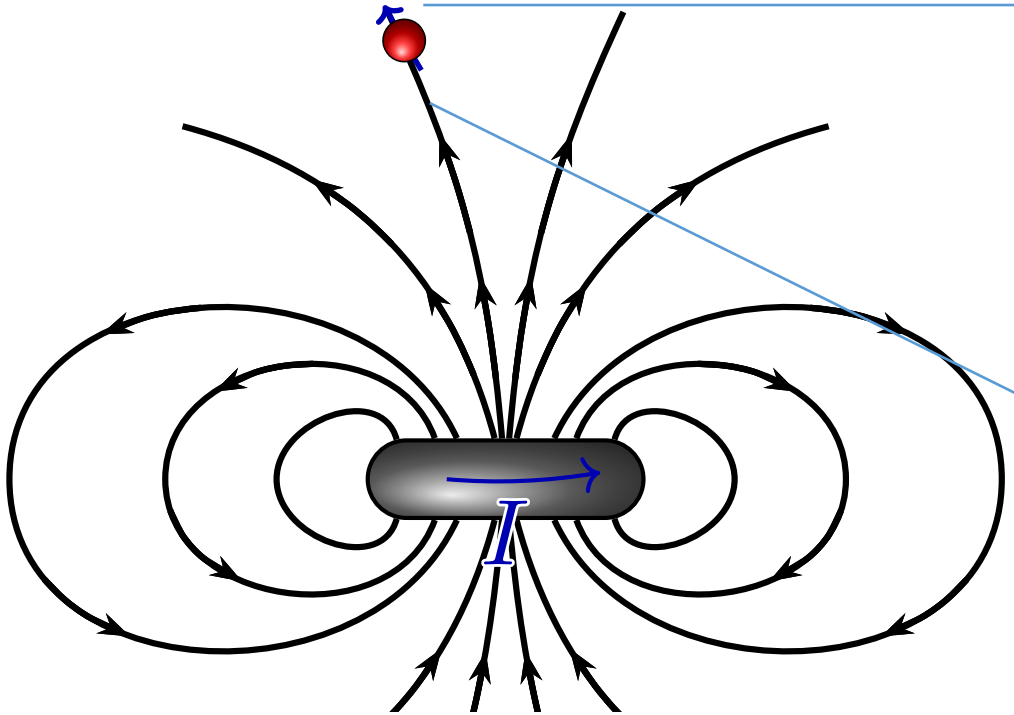
Classically Non-Describable Two Valuedness

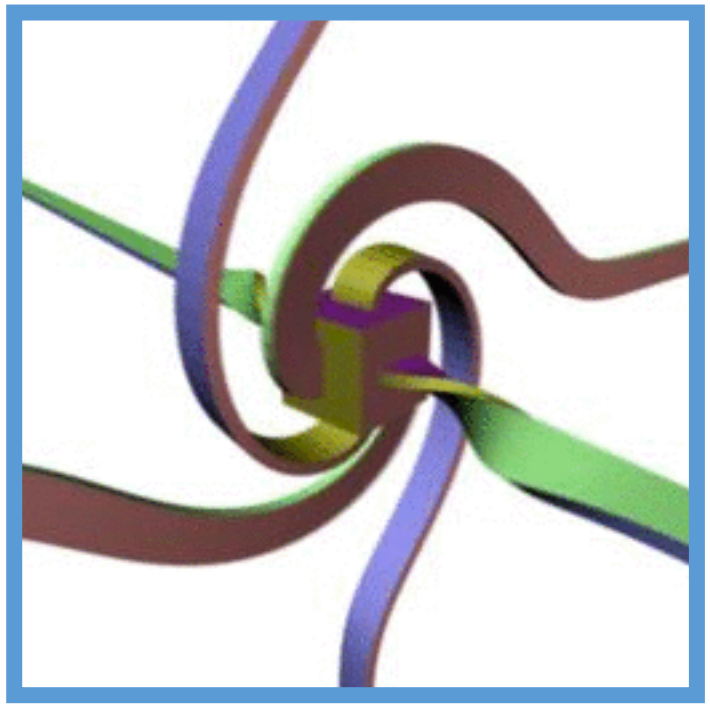




(Anomalous Zeeman Effect) In order to explain the order of magnitude the electrons would have to be spinning faster then speed of light!!!

Classically Non-Describable Two Valuedness





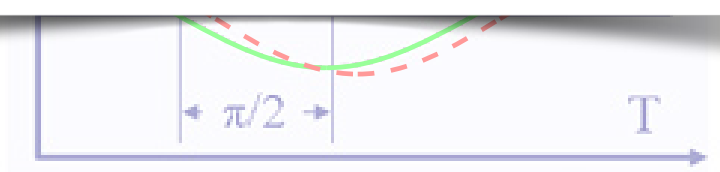
1) Entirely Quantum Mechanical Property like mass (nothing spins) - responsible for structure of all matter
2) however it behaves like angular momentum
3) Gives a charged particle a huge magnetic field!!!

B ∥ z: 2. B changes by ΔB:

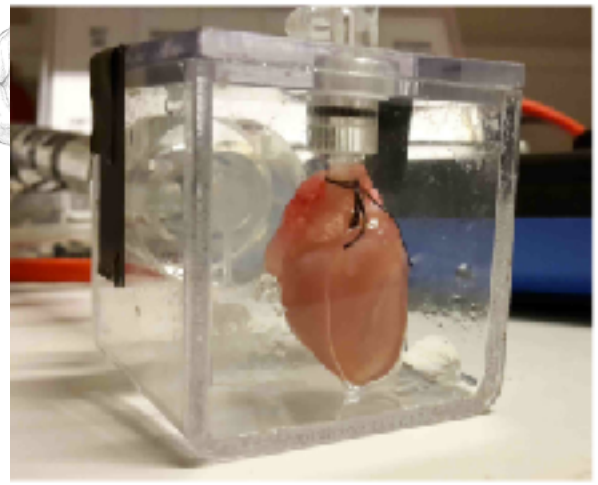
They have been used to probe:

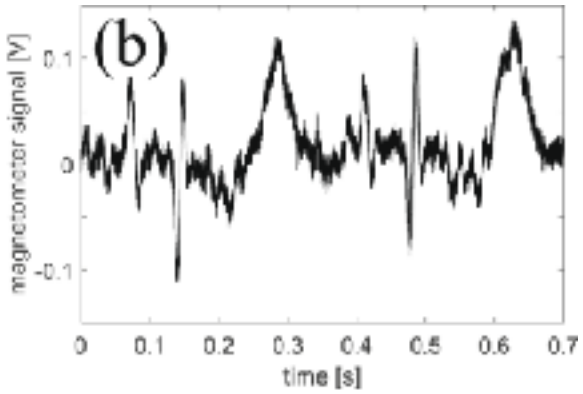
1) Heart
2) Brain
3) with potential for lung, muscles, cerebrospinal fluid, etc
4) ex: SQUIDS, SERF, Proton Magnetometers

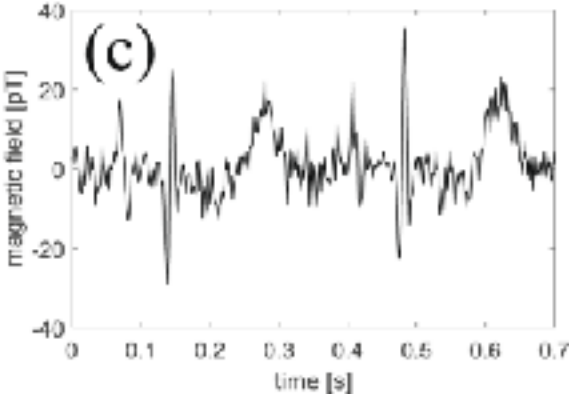
However they are limited by fundamental quantum noise!!!



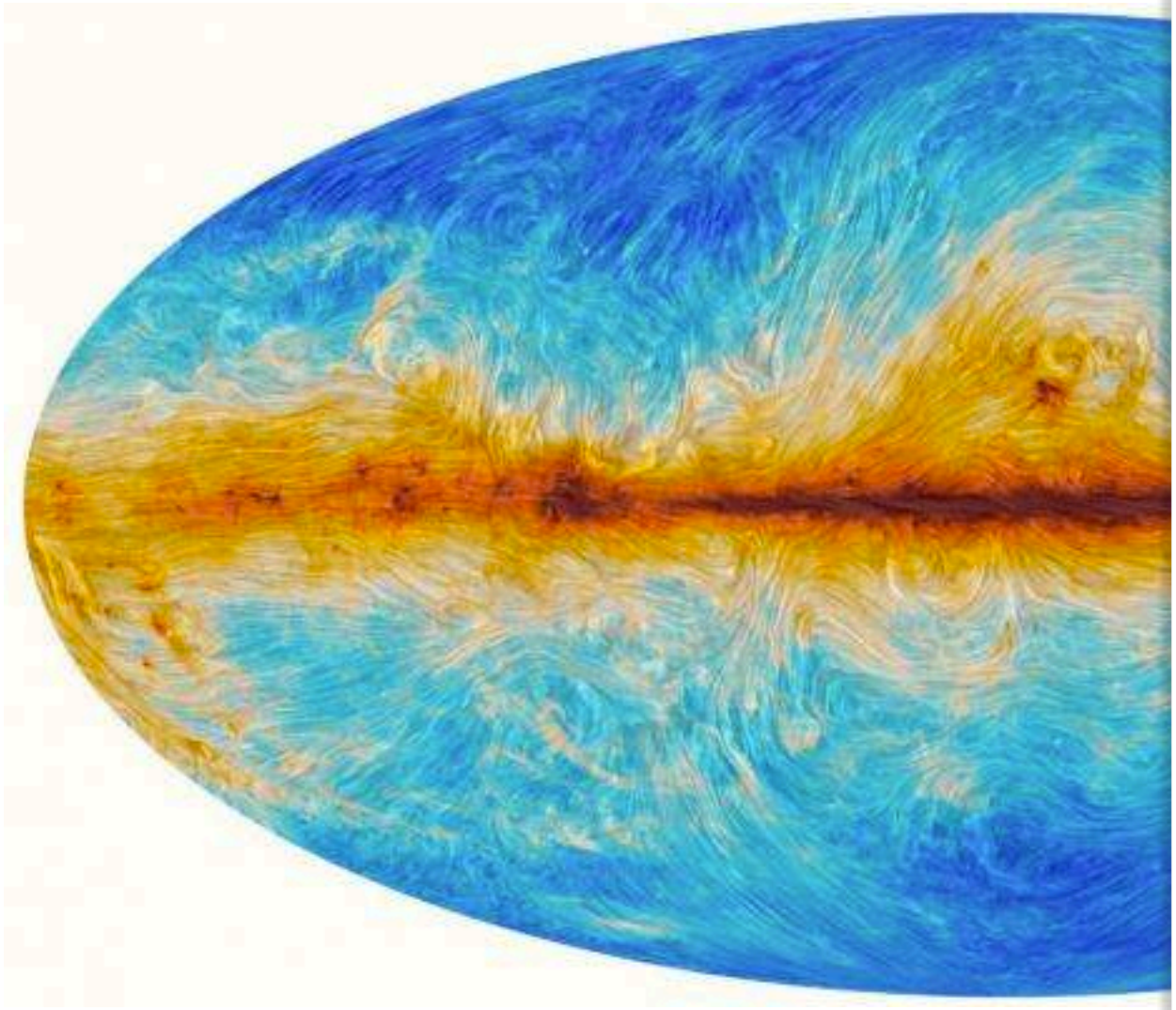
Heart



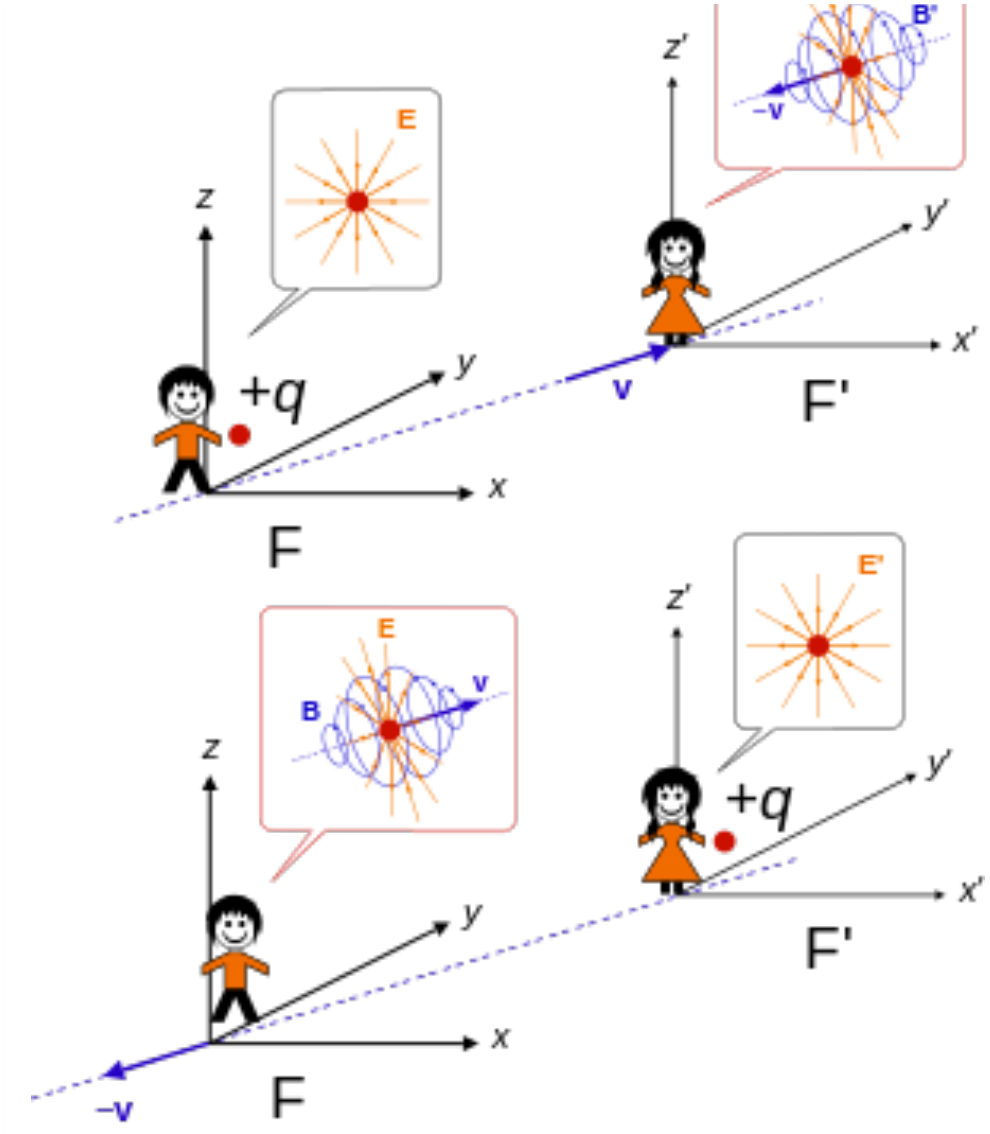




Brain

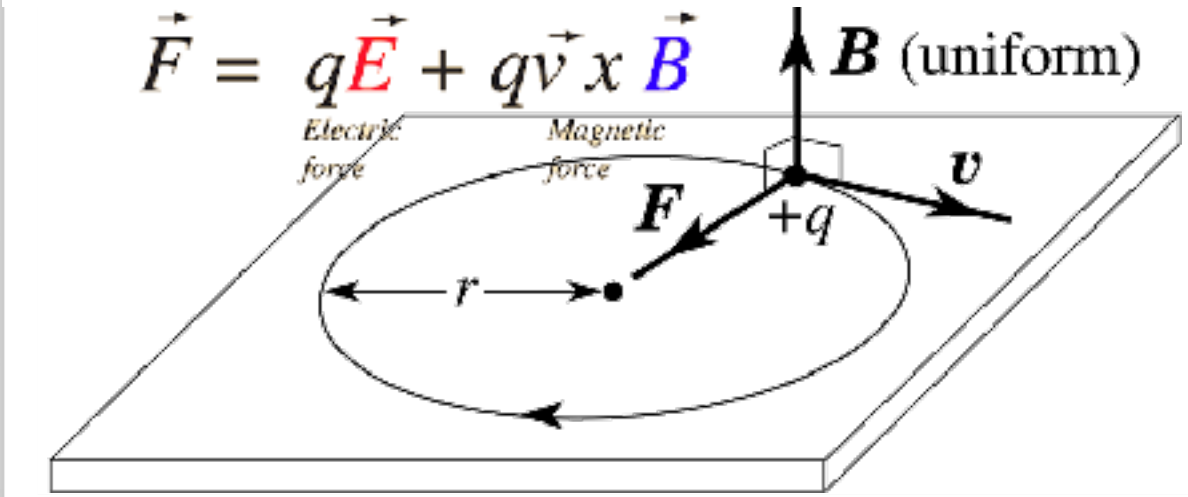


Exists Relativistically

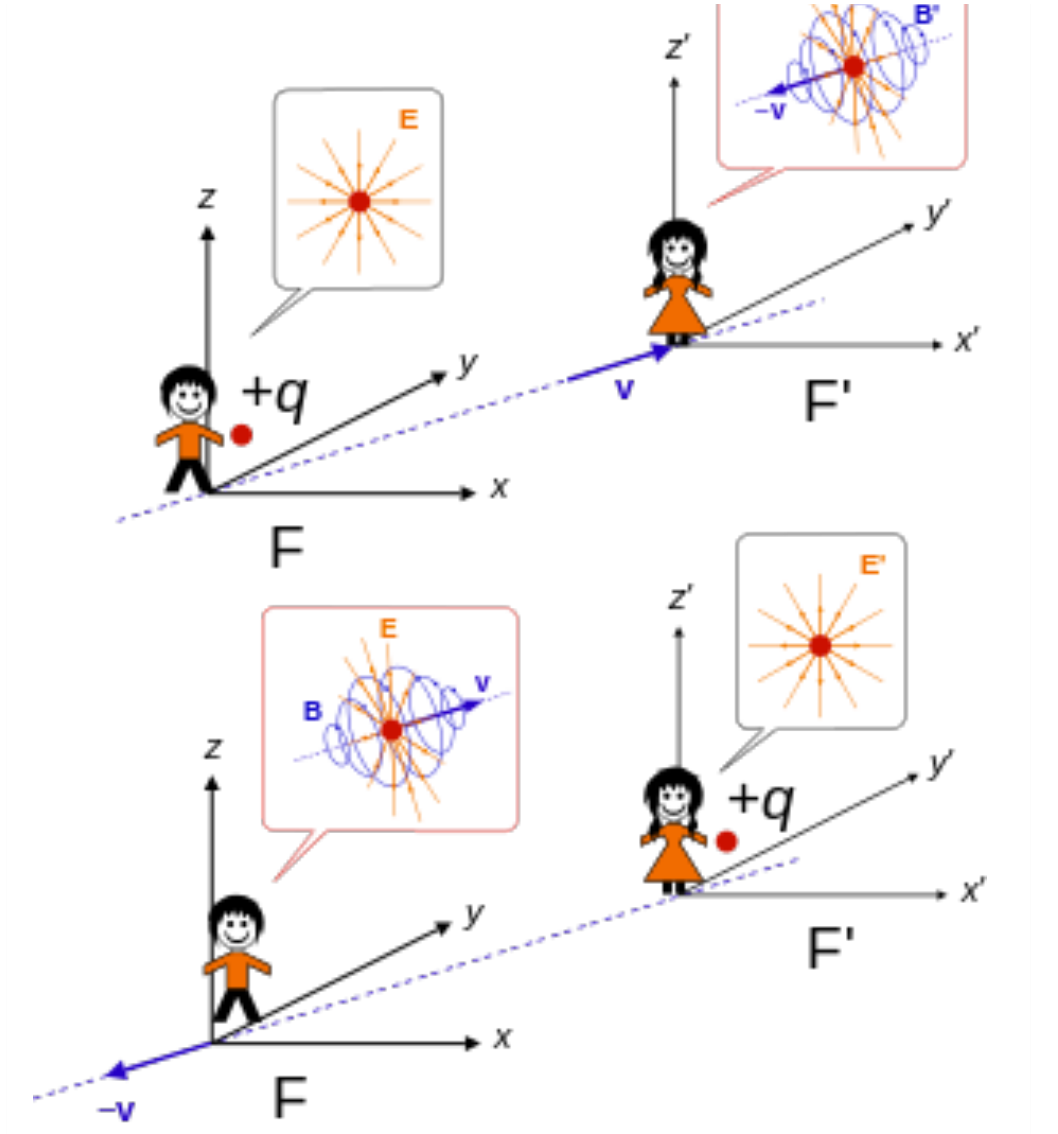


GLOphotonics

Requires 3+1 Dimensions

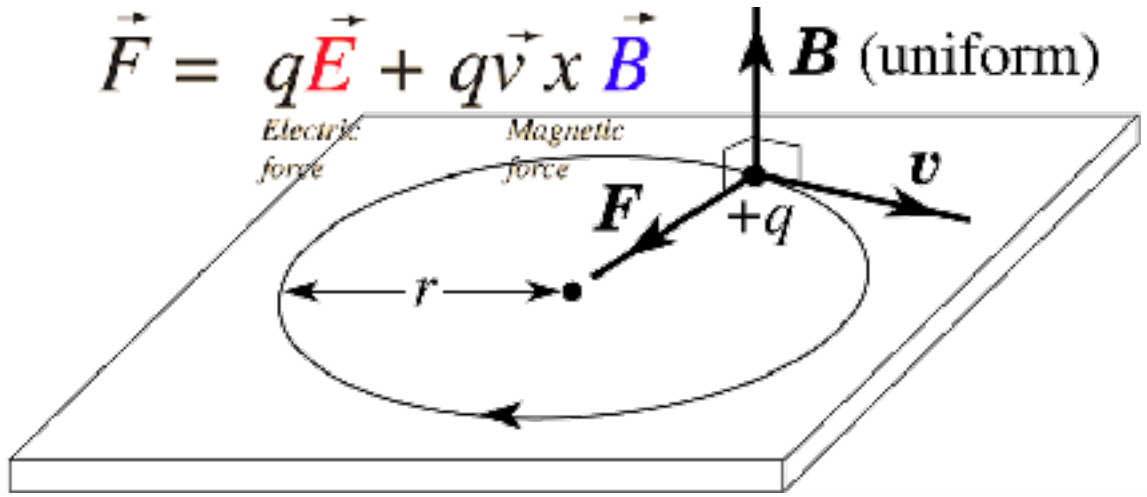


Exists Relativistically

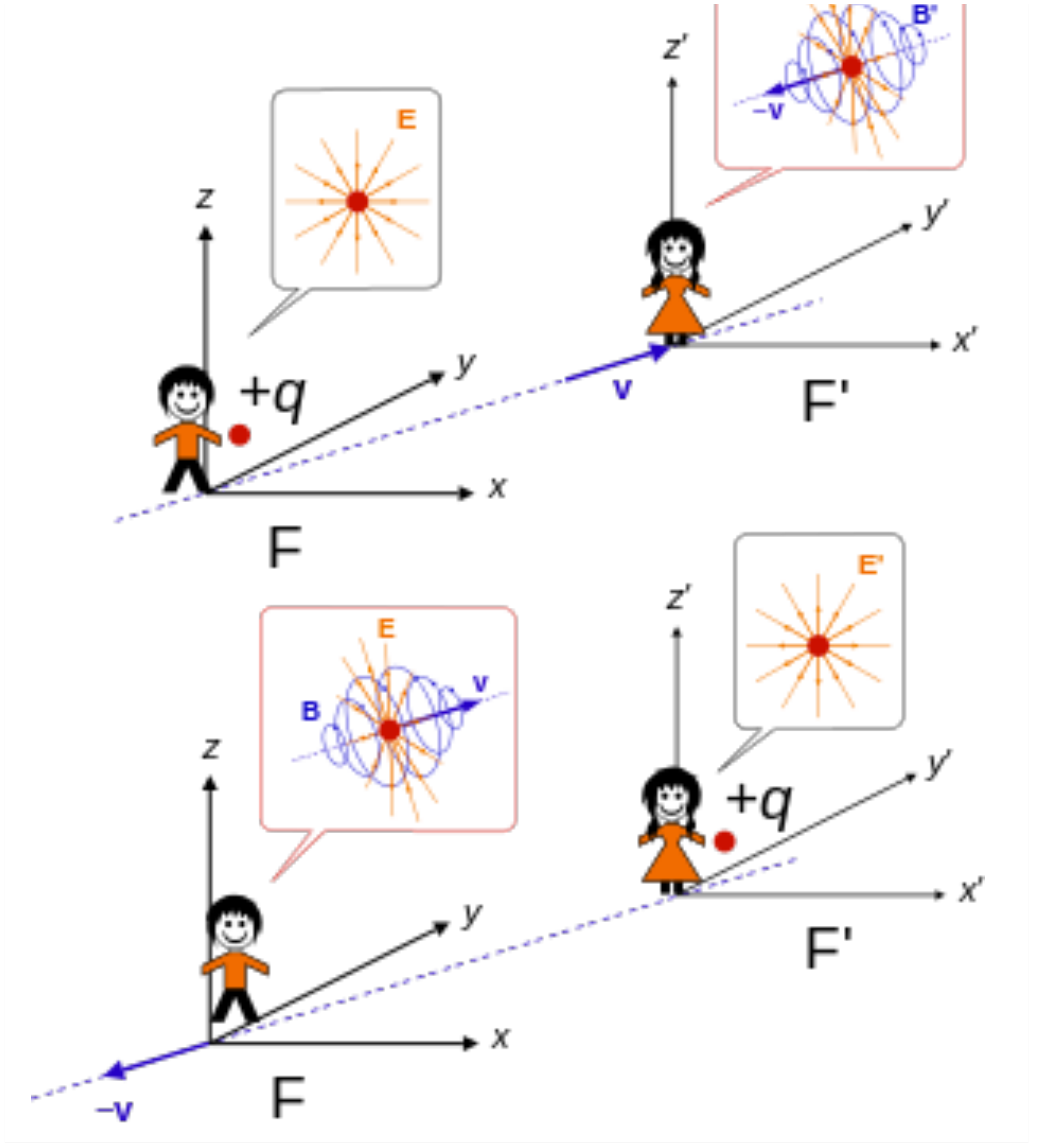


GLOphotonics

Requires 3+1 Dimensions

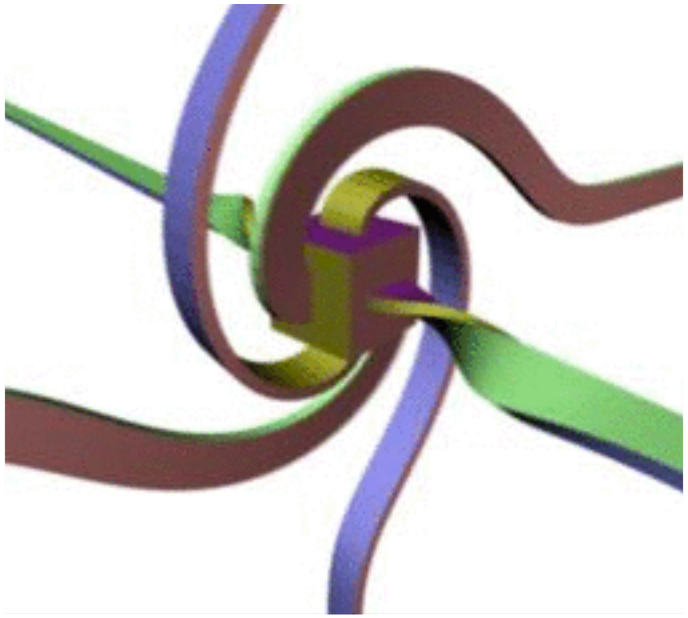


Exists Relativistically



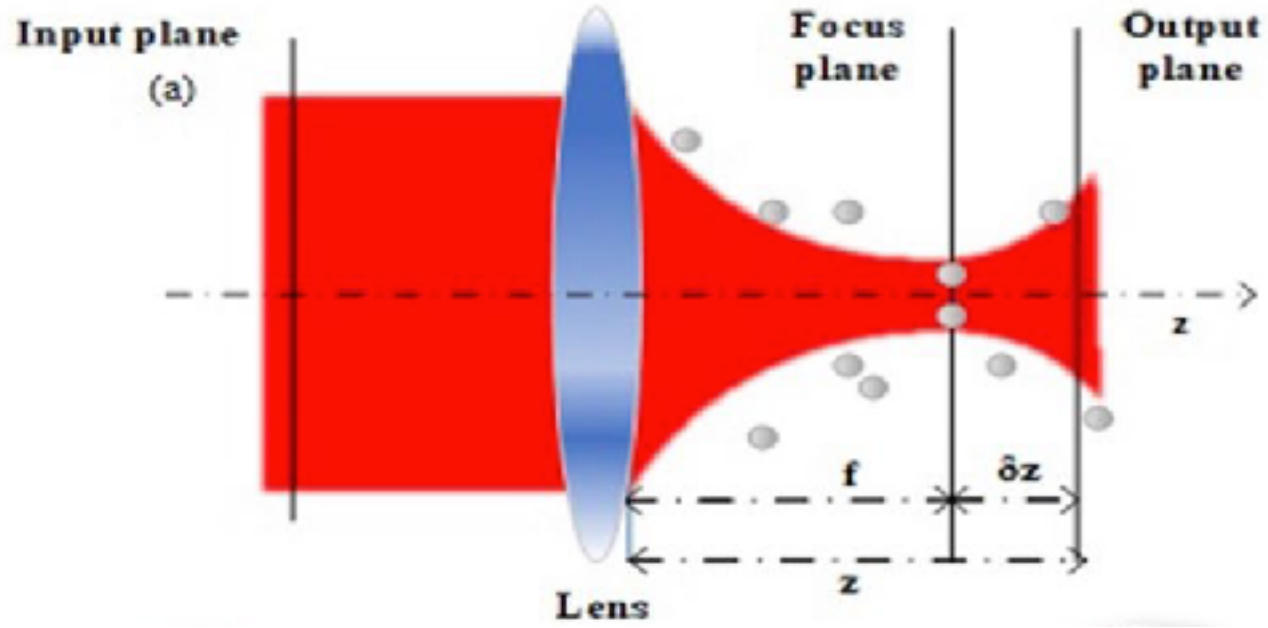
Classically Non-Describable Two Valuedness

1) Entirely Quantum Mechanical Property
2) behaves relativistically
3) imparts Huge Magnetic Field!!!



GLOphotonics

Increasing Atom-Light Interactions Key Enabling Technology

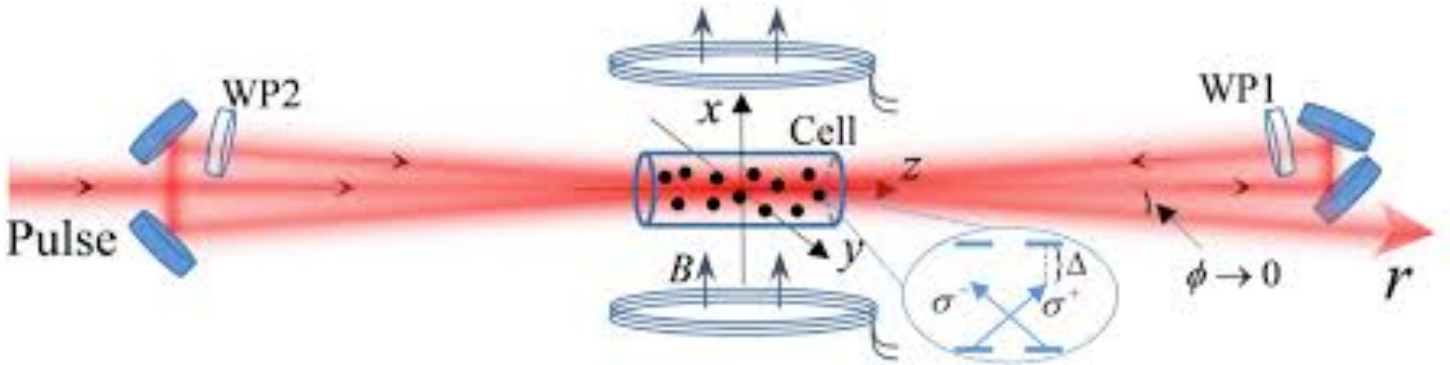


Need to Enhance Optical Depth!!!

- limited by finite overlap between atoms and laser

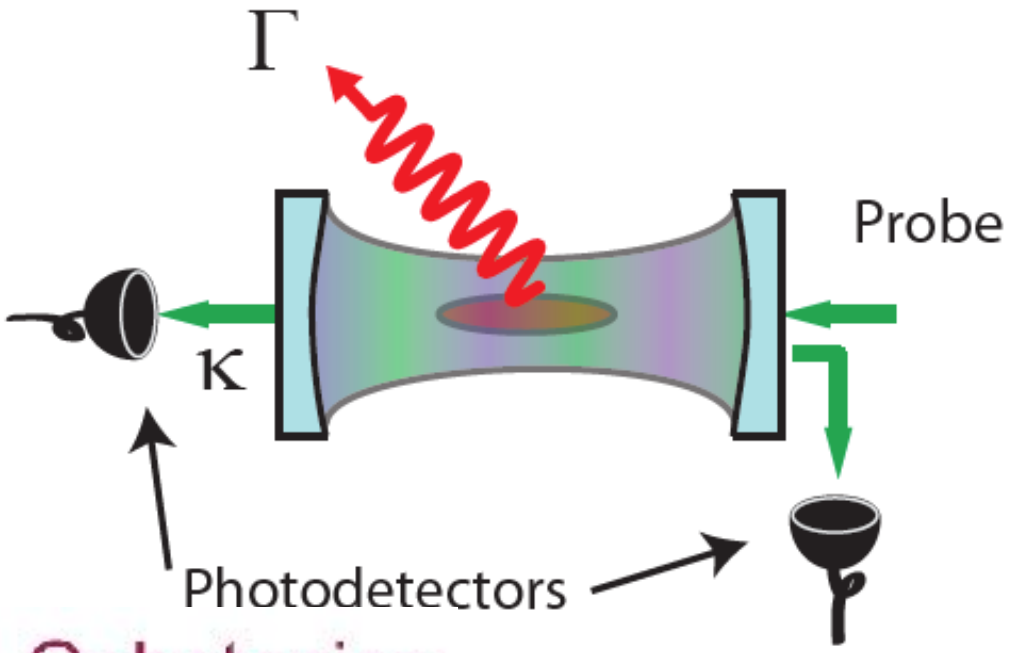
GLOphotonics

Increasing Atom-Light Interactions Key Enabling Technology



Multi-Pass Geometry

- simple geometry
- limited enhancement



Cavity Enhancement:

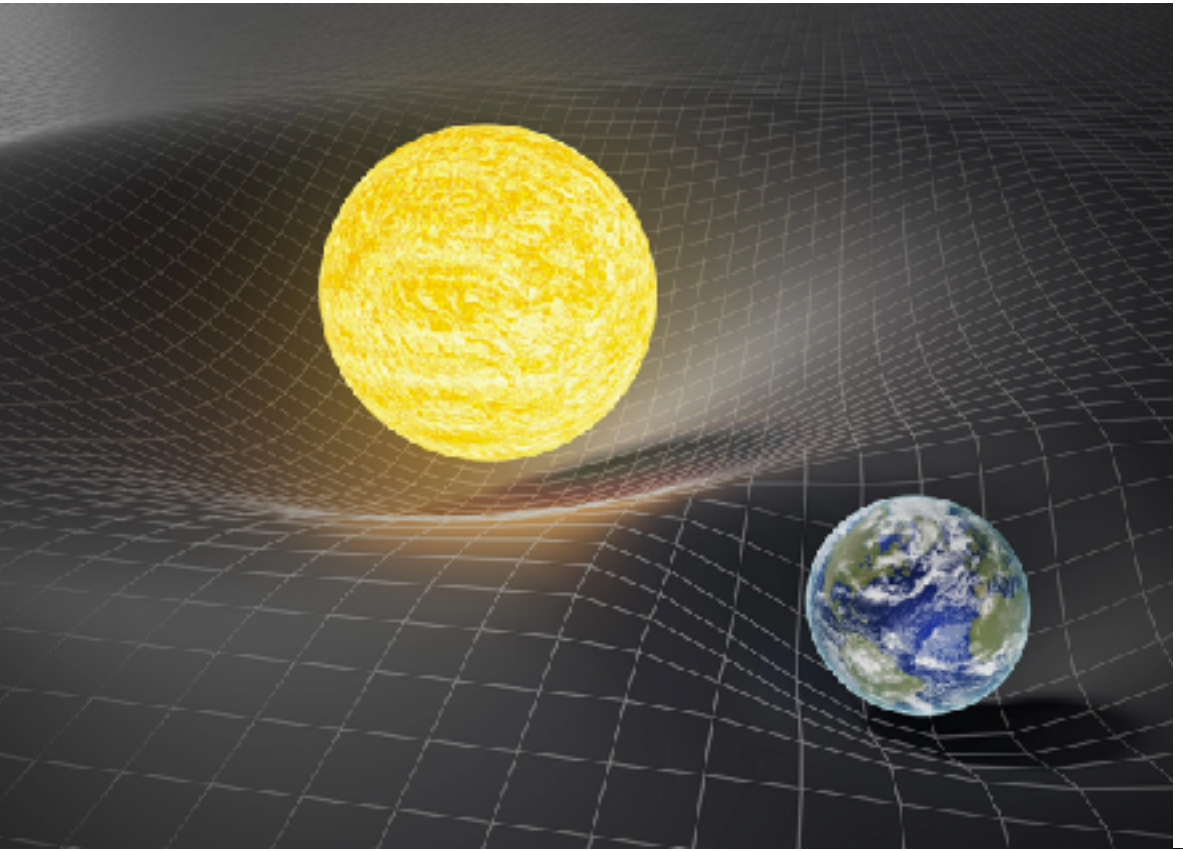
- factors of 100,000
- complex locking
- stability issues

GLOphotonics

Many cutting-edge quantum technologies offer a glimpse into the world of gravity

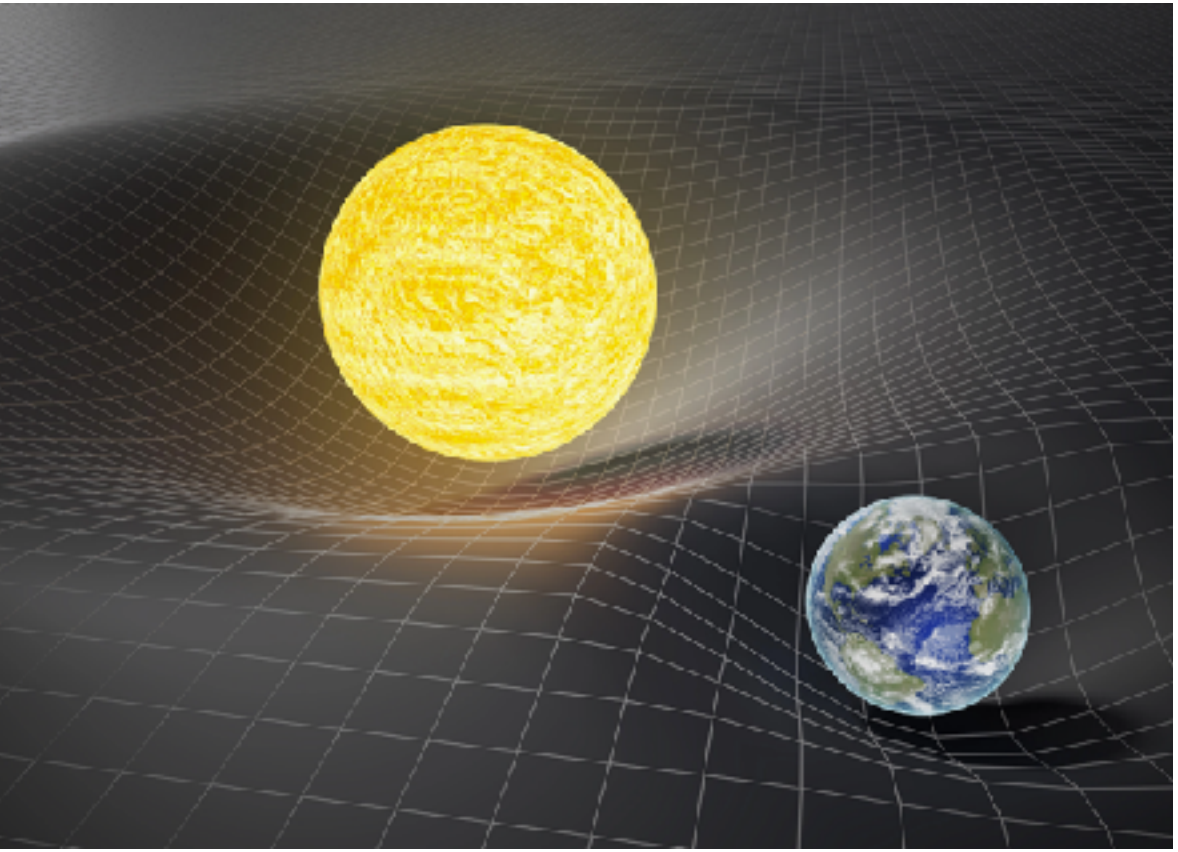
GLOphotonics

Many cutting-edge quantum technologies offer a glimpse into the world of gravity

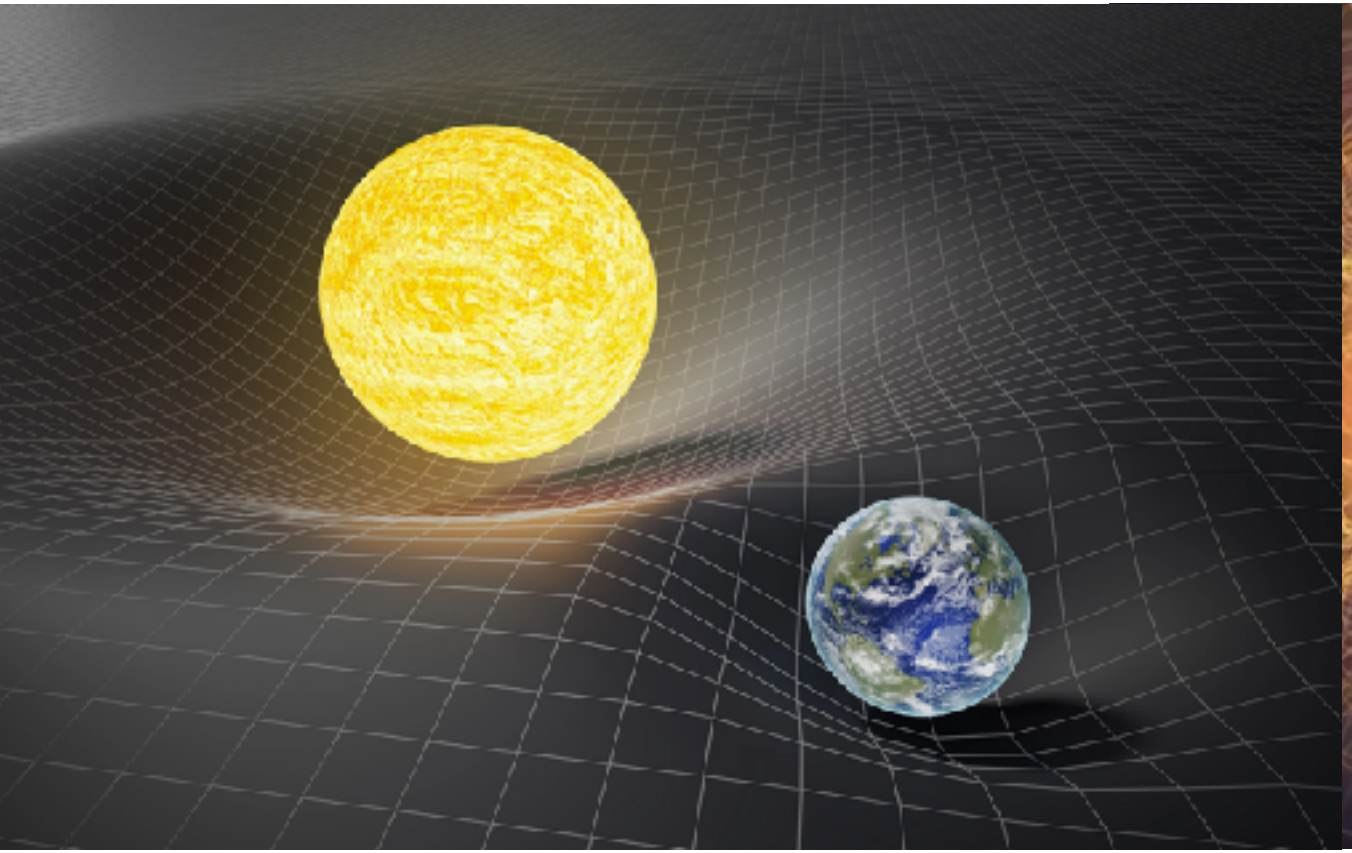


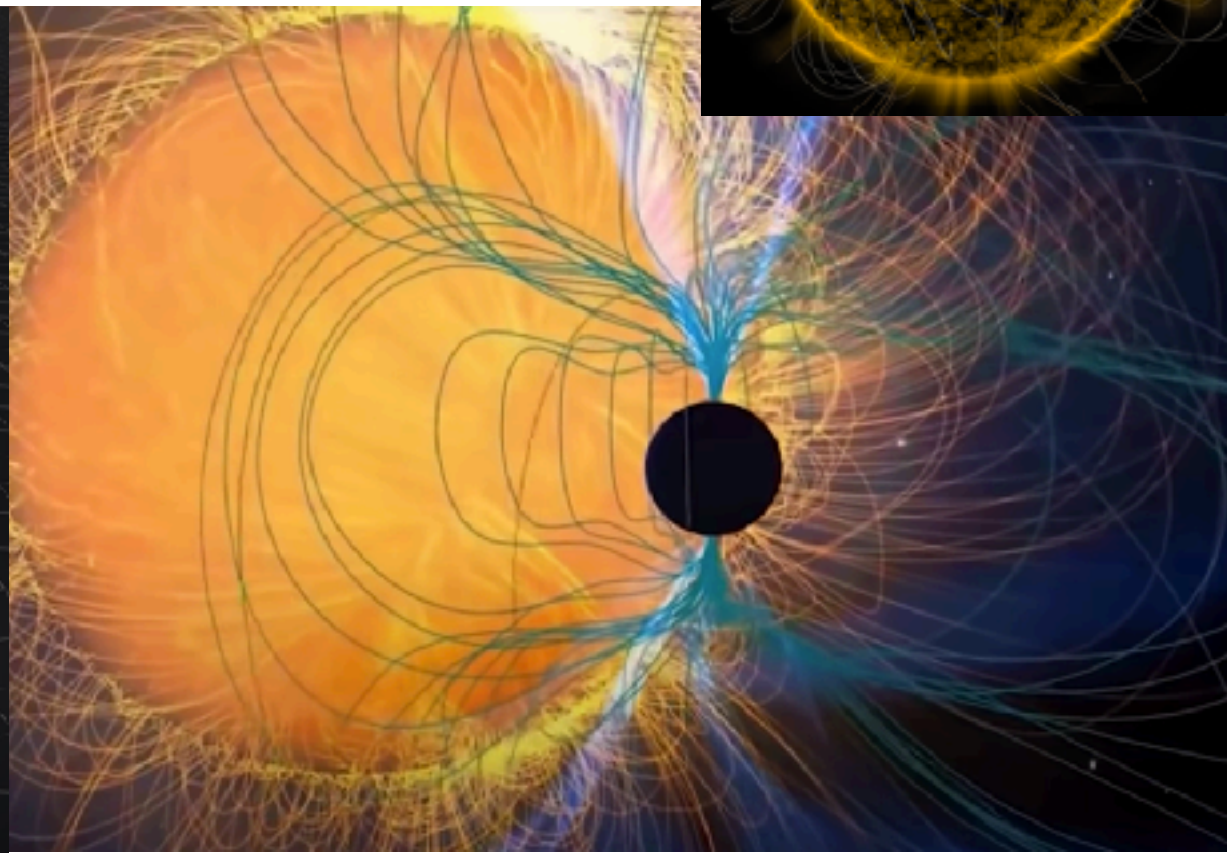
GLOphotonics

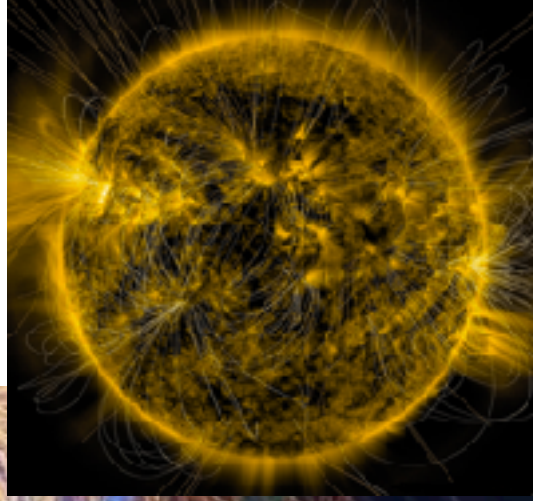
However having the ability to see Magnetic Fields can uncover unheard of beauty



From the Earth's magnetic field revealing plate techtonics to the Sun's magnetic field releasing solar flares

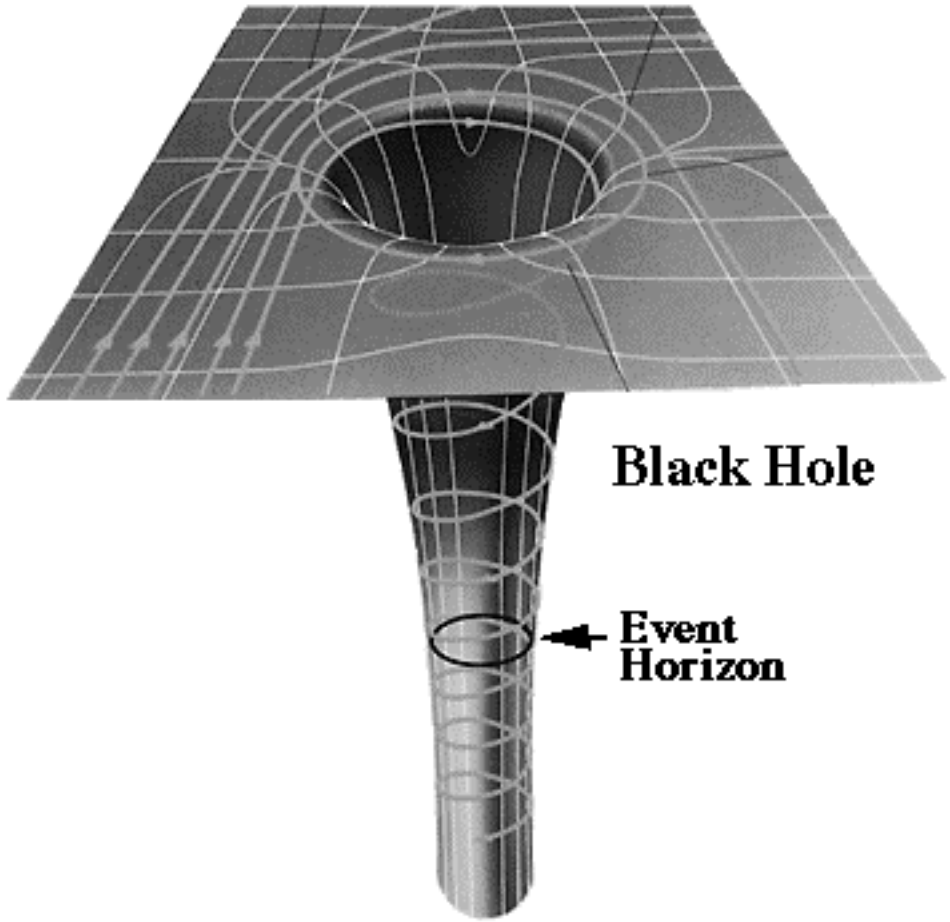


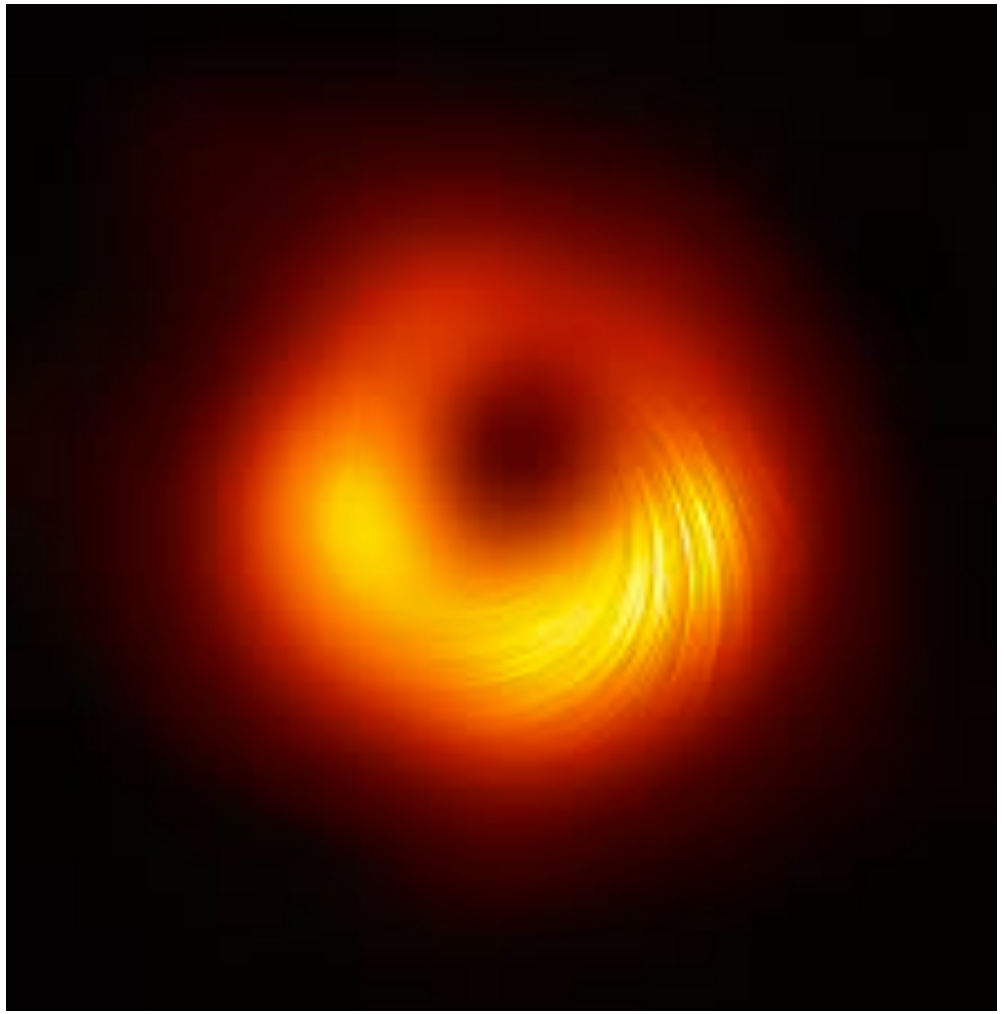




GLOphotonics

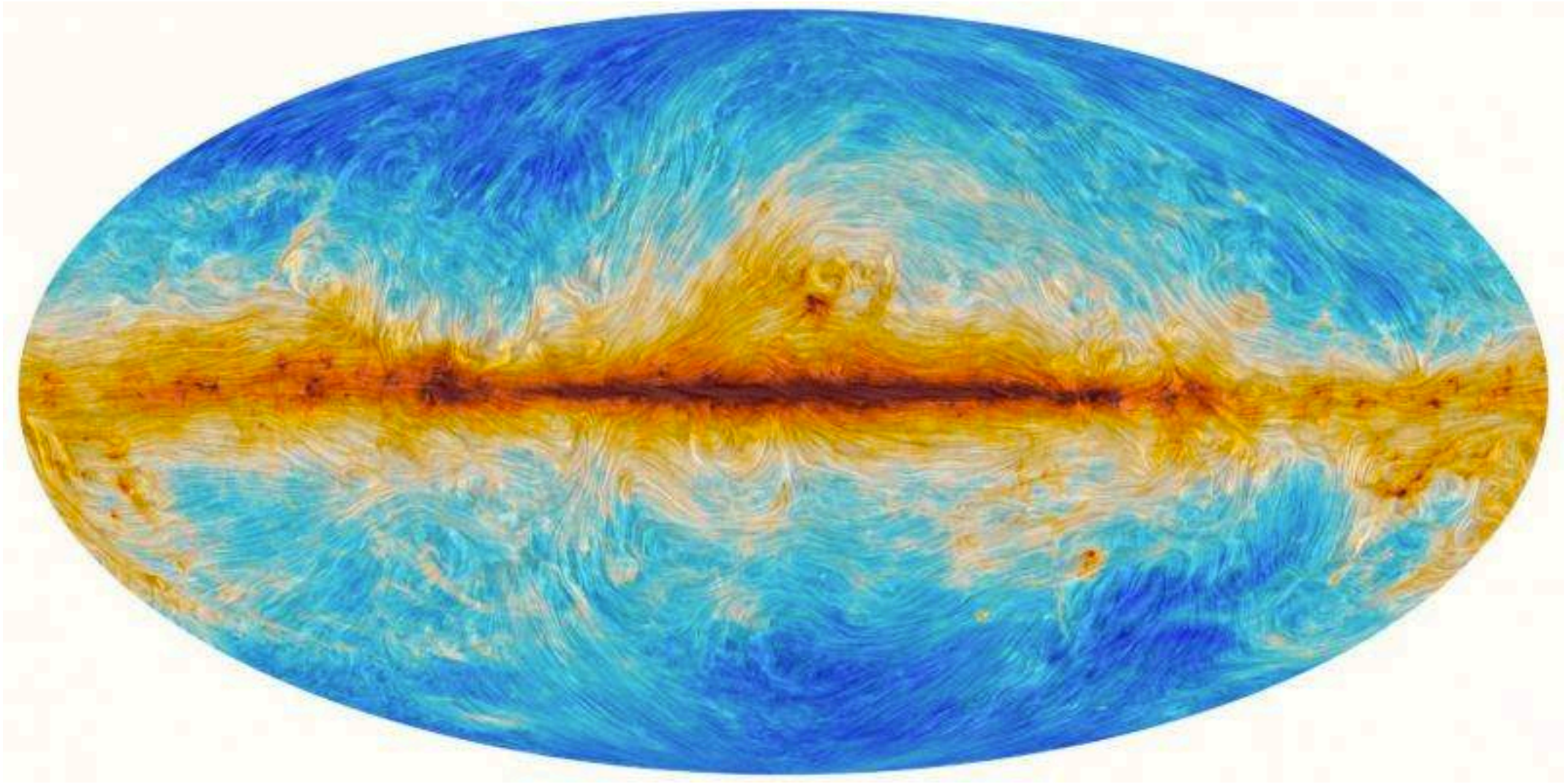
To the Heart of a Black Hole





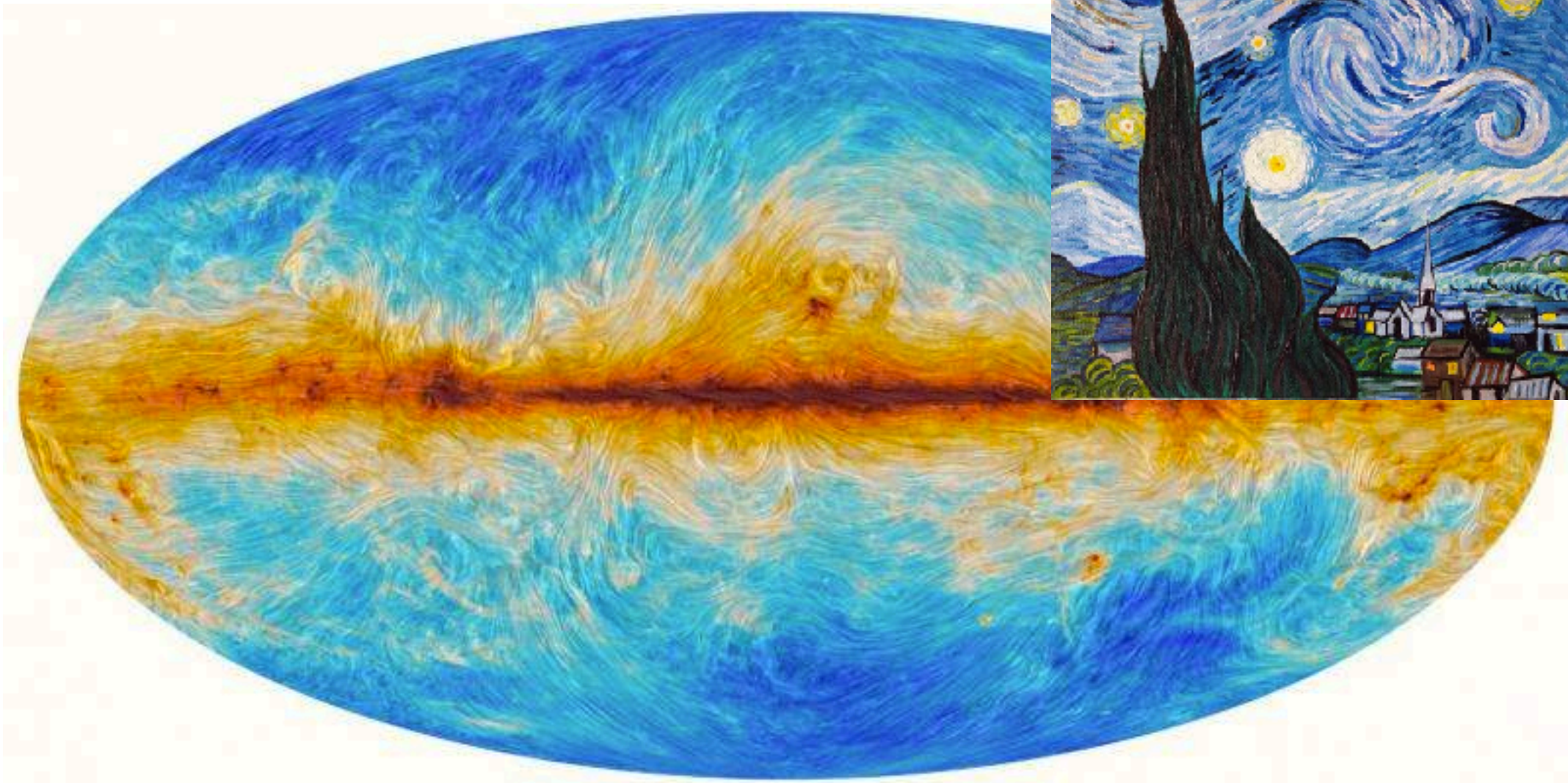
GLOphotonics

and the Universe Itself



GLOphotonics

and the Universe It



GLOphotonics

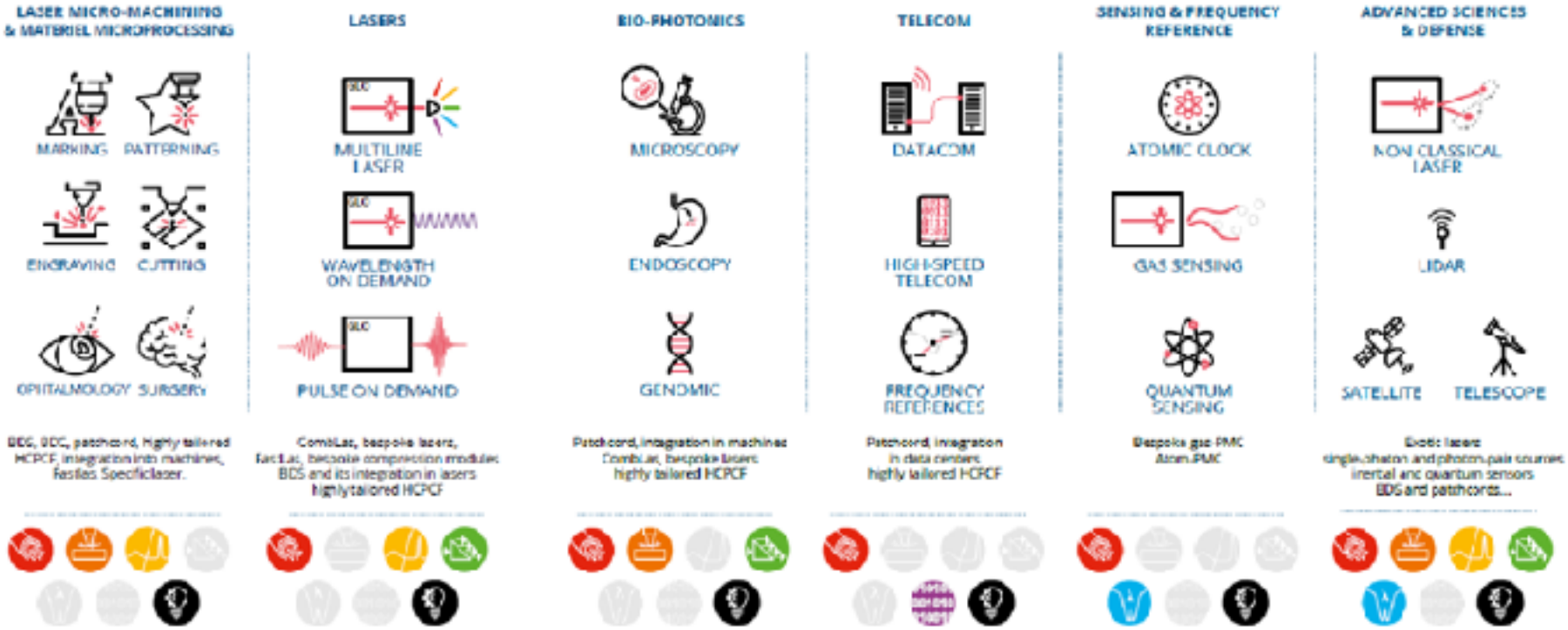
MULTISECTORIAL PRODUCT MIX

Applications

GLOphotonics HCPCF and PMC technology is equally a platform and key-enabling technology.

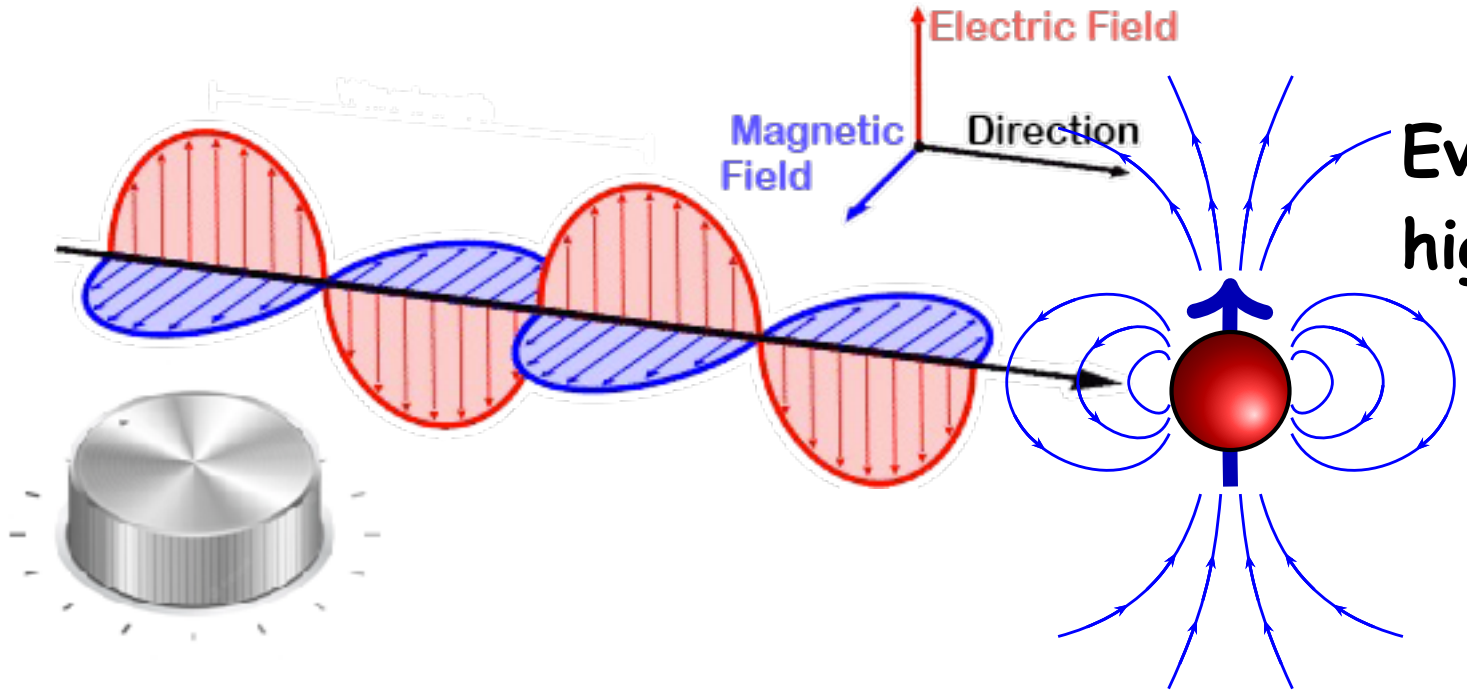
A feature, reflected in GLO photonics products, service and offering.

- **HOLLOW CORE PHOTONICS CRYSTAL FIBER & PHOTONIC MICROCELL™**
- **BEAM DELIVERY**
- **PULSE COMPRESSION**
- **FREQUENCY CONVERSION & LASERS**
- **FREQUENCY REFERENCES**
- **LOW LATENCY DATACOM**
- **TECHNOLOGY SOLUTIONS**



GLOphotonics

The Importance of Atom-Light Interactions



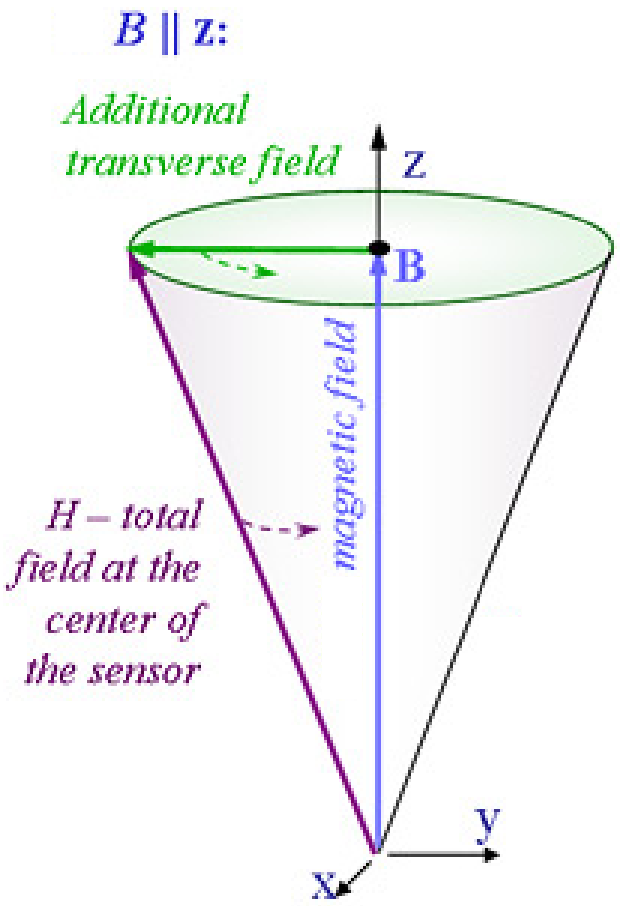
Every Step in the process requires high atom-light interactions:

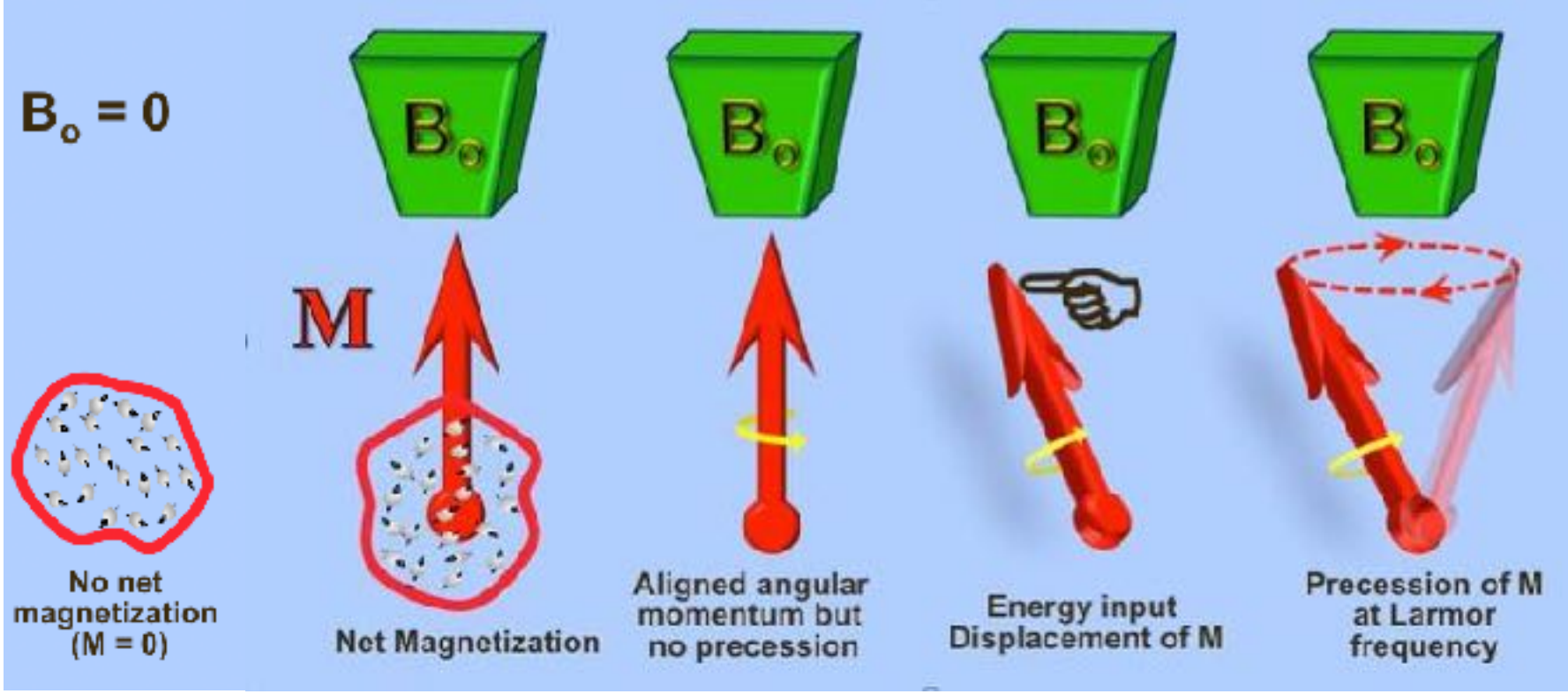
1) Preparing Quantum Spins
2) Measuring Quantum Spins
3) Beyond Quantum Limit

Magnetic Field of Light can interact with Quantum Spin of Particle

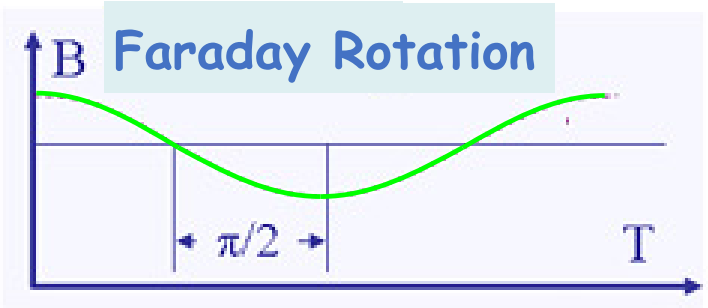
→ allowing a knob to control and measure quantum spin

GLOphotonics





Convert Magnetic Field to Frequencies, which can be measured with metrological precision

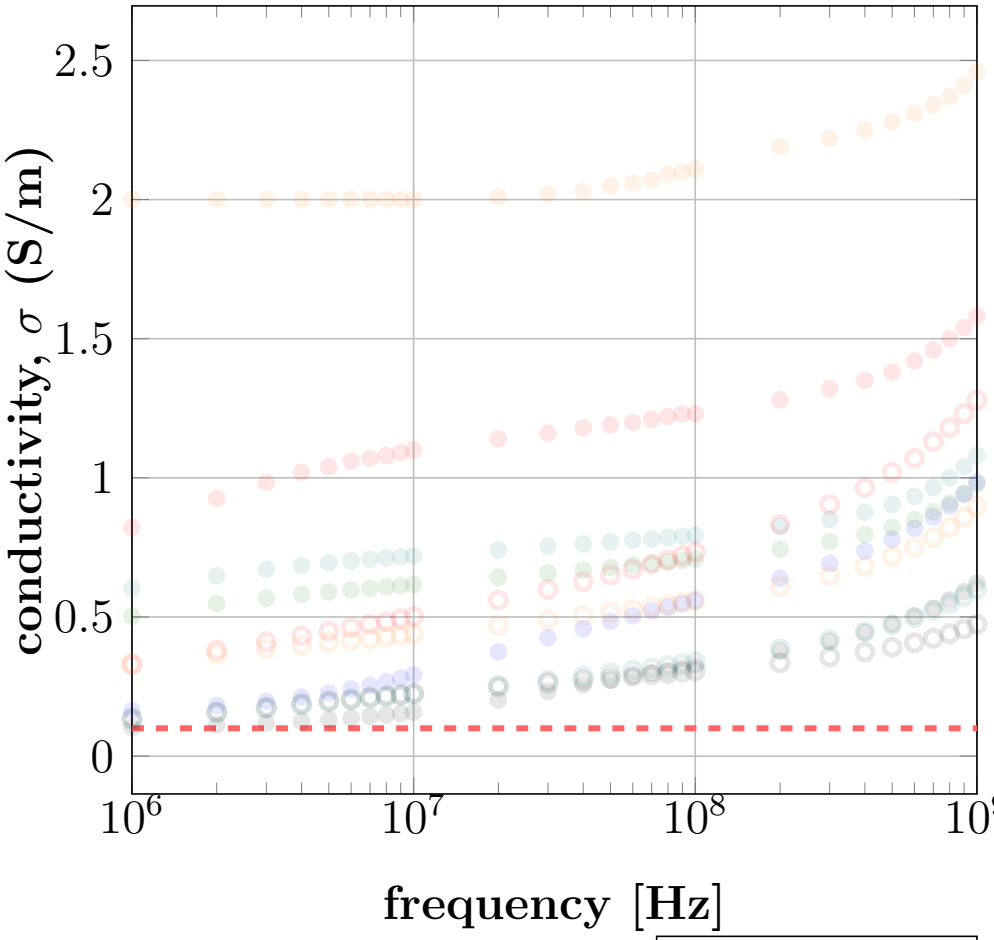


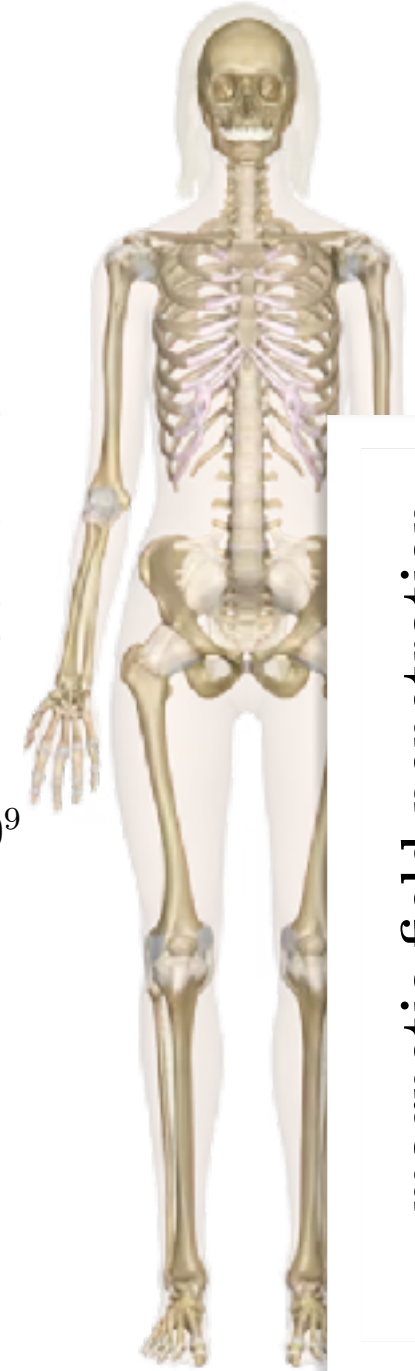
"Never measure anything but frequency!"

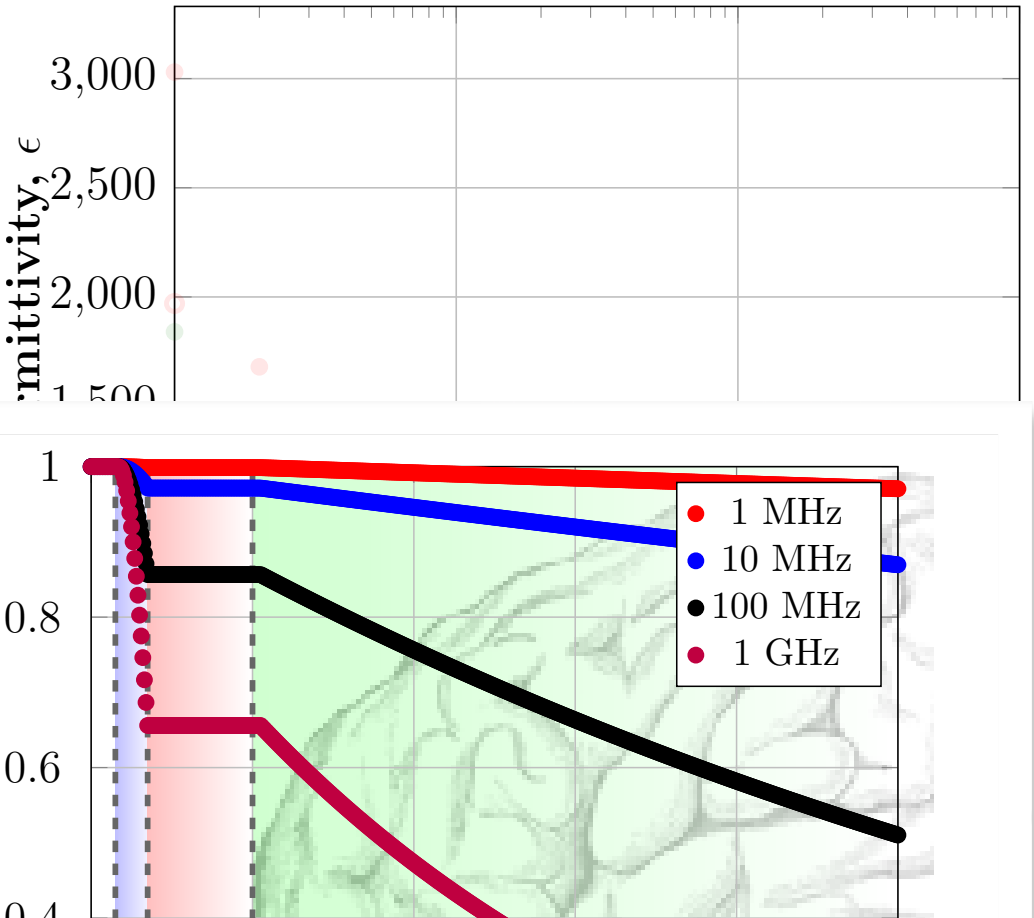
Arthur Schawlow

(co-inventor of laser with Townes, winner of Nobel Prize in 1981)

GLOphotonics







GLOphotonics