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**What is a
quantum sensor?**

**TQCI seminar
14/11/2024**

Organized by



QUANTUM PERSPECTIVES



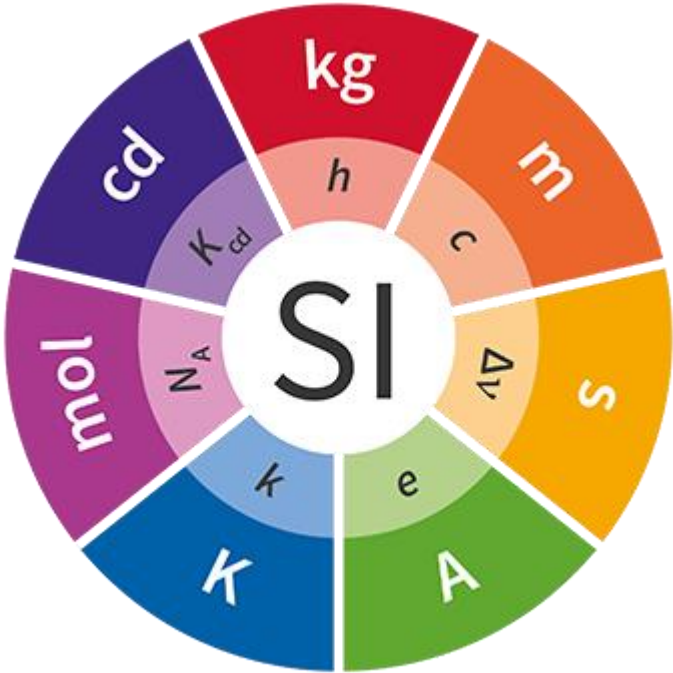
OVER 3 TO 5 YEARS

With the kind
support of



Romain Kukla
Quantum expert
Naval Group

MAIN SUCCESS OF QUANTUM METROLOGY



Units	Defining constants	Symbol	Numerical value
kilogram	Planck constant	h	$6,626\ 070\ 15 \times 10^{-34} \text{ J s}$
metre	Speed of light in vacuum	c	$299\ 792\ 458 \text{ m s}^{-1}$
second	Hyperfine Transition frequency of caesium atom	$\Delta\nu_{Cs}$	$9\ 192\ 631\ 770 \text{ Hz}$
ampere	Elementary charge	e	$1,602\ 176\ 634 \times 10^{-19} \text{ C}$
kelvin	Boltzmann constant	k	$1,380\ 649 \times 10^{-23} \text{ J K}^{-1}$
mole	Avogadro constant	N_A	$6,022\ 140\ 76 \times 10^{23} \text{ mol}^{-1}$
candela	Luminous efficacy	K_{Cd}	683 lm W^{-1}

from LNE website

ISU since 2019



Size, volume, wavelength, temperature, density, concentration, luminosity, flow, time, acceleration, weight, magnetization, pressure, speed, displacement, electrical potential, altitude, frequency, voltage, sound level, position, resistance, depth

There are so many physical quantities to monitor

... a lot more sensors available

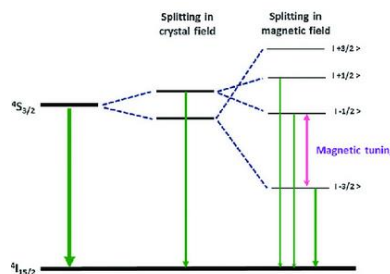
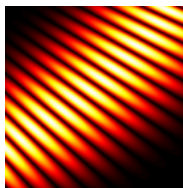
... depending on the experimental environment

... and on the intended measurement characteristics

Quantum sensors are new devices to add to our toolbox

Quantum sensors

- Position, time, frequency
- Speed, acceleration, rotation
- Electromagnetic and gravitationnal fields
- Temperature, pression
- Luminosity

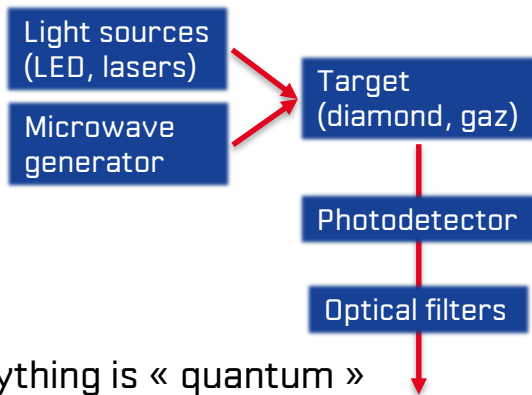


Clock
 Accelerometer, gyrometer
 Magnetometer
 Antenna, RF filter, gravimeter
 Photodetector, LED
 Strain sensor, resistive sensor

> Precise measurements possible via optical or atomic interferometry and direct coupling of the probed phenomena with the particle states.

Quantum sensors

> The setup exploits fundamental quantum mechanisms which embed the physical properties to be measured at the particle scale.



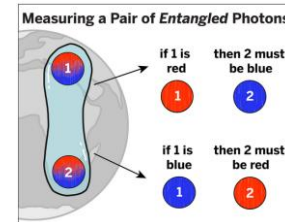
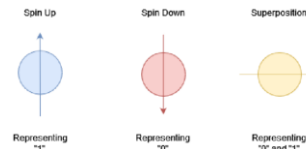
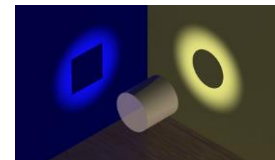
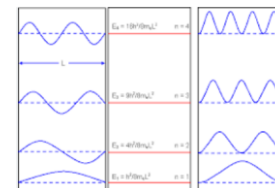
Everything is « quantum »

Quantization

Wave-particle duality

Superposition

Entanglement

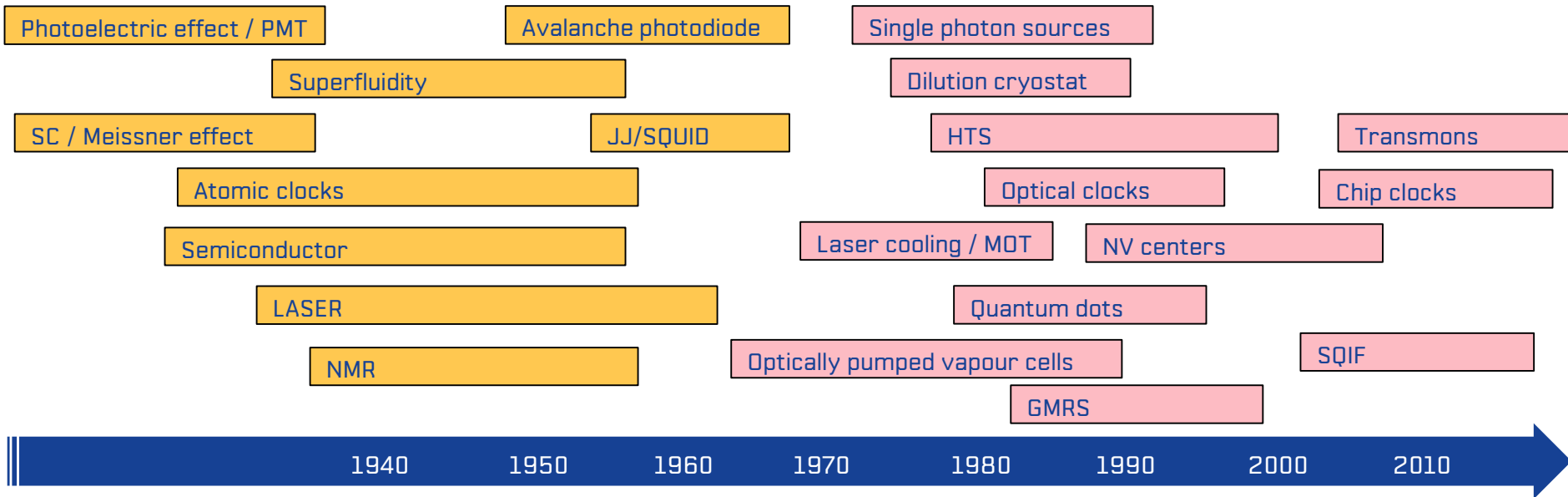


TIMESCALE OF QUANTUM TECHNOLOGIES

First Generation of technologies (basic use of quantum effects)

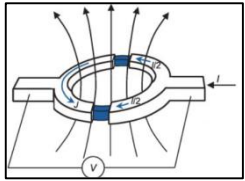
vs Second Generation (dedicated use of superposition, entanglement + individual manipulation)

Where does it start and when does it end ?



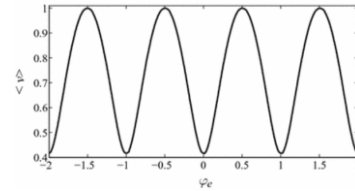
QUANTUM DEPHASING EFFECTS

Related to EM fields

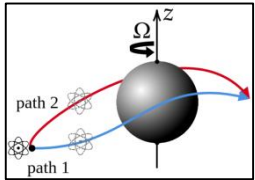


SQUID loops sensitive to incoming magnetic flux, creating a periodic dephasing of the outgoing supercurrent.

Relative magnetometers / RF antenna with cryogenics

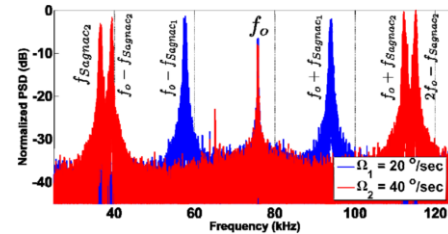


Related to optical wavelengths

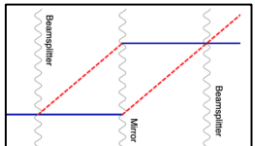


RLG and **FOG** sensitive to rotations perpendicular to the optical loop, creating a dephasing between the laser beams.

Room temperature stable gyroscopes

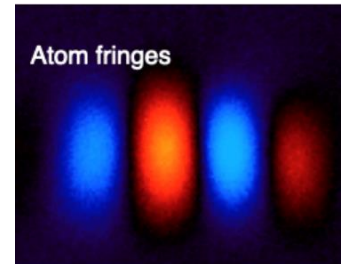


Related to atomic states



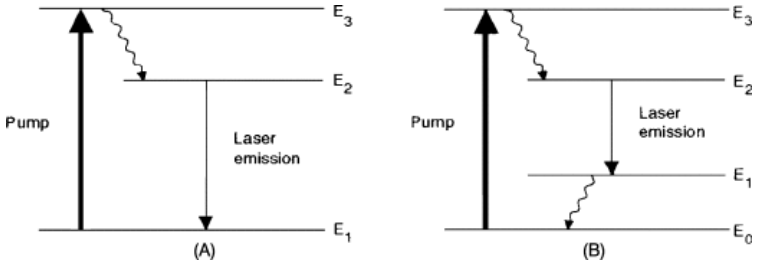
Cold/trapped atoms and ions, in hyperfine states sensitive to EM fields, accelerations, rotations perpendicular to the motion, creating a dephasing between two populations.

High-precision clocks, gravimeters, IMUs with magneto-optical traps



OPTICAL PUMPING CYCLES

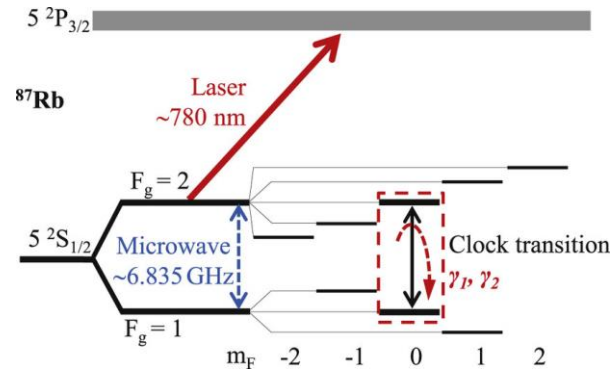
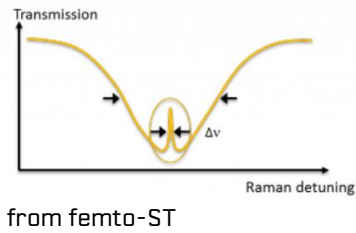
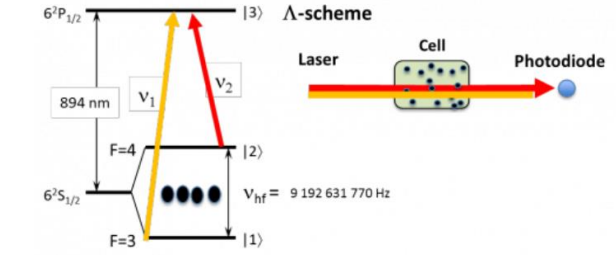
Fine or hyperfine level transitions, when correctly engineered, can be used to probe atomic states whose properties are correlated to a physical quantity.



> These readout techniques bring information from the quantum world to the macroscopic scale

■ Optical pumping

■ Double resonances (ex. NV centers)



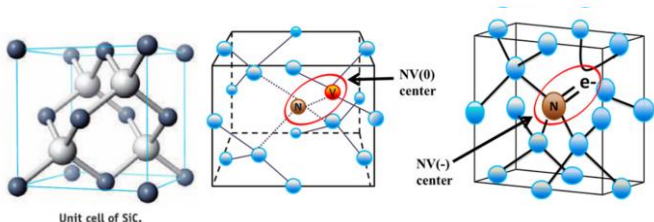
■ Microwave probing of HF transitions (ex. atomic clocks)

■ Dark state creation (ex. CPT cells)

ATOMIC ENHANCEMENT TECHNIQUES

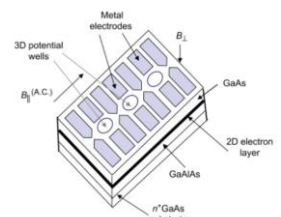
When nature does not give the structure fitted for a measurement, why not forcing it to exist ?

Artificial atoms



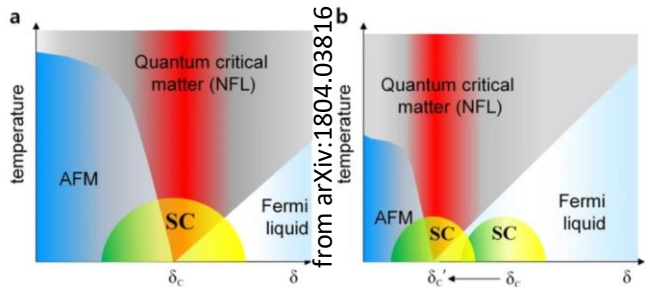
> Next generation quantum (sensing) technologies will definitely come from such nature-bending processes to design specific behaviours.

SiC and NV color centers



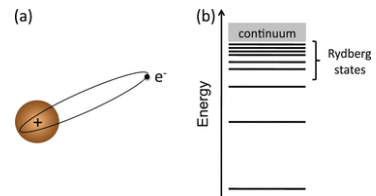
Quantum dots

Quantum states of matter

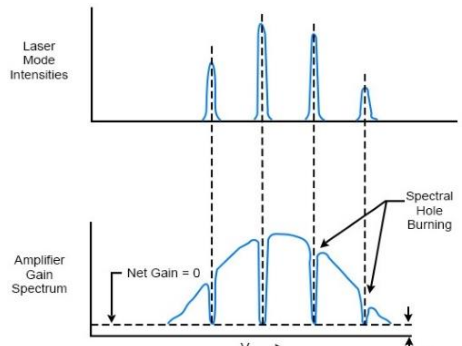


Phase transition induced by doping

Giant atoms



Ultrapure laser



Frequency stabilization using SHB

And then mix all these elements

... add some quantum networks to distribute the states

... maybe send them to QC for « quantum analog treatments »

... ..

> As industrial end users are not fundamental physics researchers, keep it mind that sensor improvement is not the only way to push further the limit

- if and only if there is indeed a real need to go deeper ! -

▼
**Thank you for
your attention**