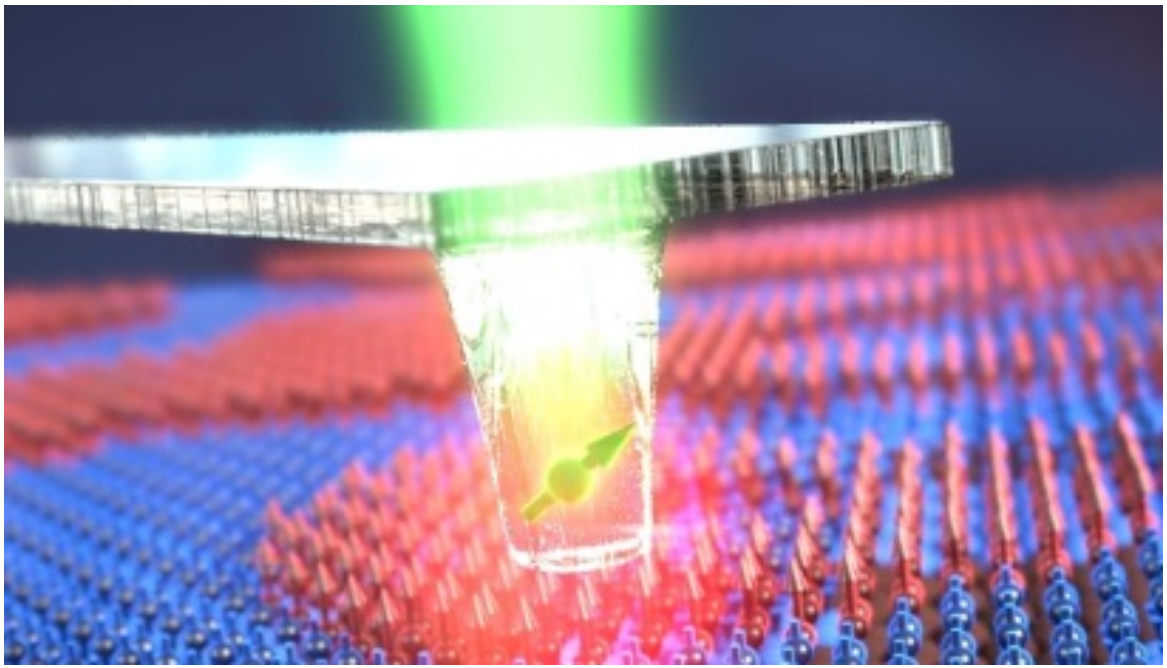
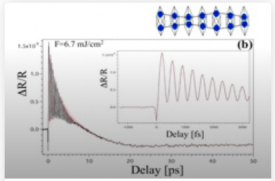
MAGNETOQUANT Project

Davide Boschetto

LOA, Laboratoire d'Optique Appliquée, ENSTA Paris/Ecole Polytechnique/CNRS/Institut Polytechnique de Paris, Palaiseau, France



New group at LOA:
Ultrafast optics for QUANTUM materials



Femtosecond spectroscopy on quantum materials

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Quantum sensors

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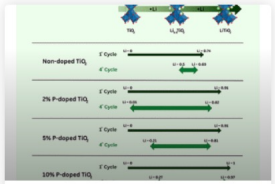

Ultrafast Dynamics in Rechargeable Batteries

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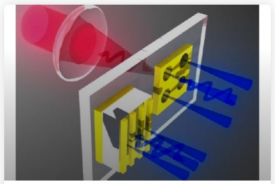

Attosecond quantum photonics

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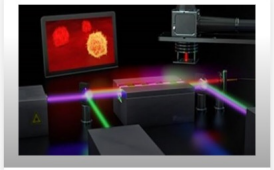

Quantum and ghost imaging

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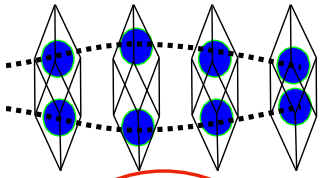
Group Members

Davide Boschetto, Professor at ENSTA Paris, Group Leader
Hamed Merdji, Research Director at École Polytechnique
Emmanuel Péronne, CNRS Research Scientist
Mateusz Weis, PostDoc
Marie Cherasse, PostDoc
Amélie Kies, PhD Student
Pierrick Lample, PhD Student
Ayoub EL Bendali, PhD Student
David Theidel, PhD Student
Viviane Cotte, PostDoc
Houssna Griguer, PhD Student
Partheepan Sentilnathan, Engineer
Filippo Calavero, M2 Student
Adam Merdji-Larue, PhD Student
Olena Turianska, PostDoc
Damir Pinek, PostDoc

Time scales



10^{-18} =as | 10^{-15} =fs | 10^{-12} =ps | 10^{-9} =ns | 10^{-6} =Δs | 10^{-3} =ms | 1 s | 10^{3} ~1 h | 10^{6} ~mois | 10^{9} ~siècle | 10^{12} | 10^{15} | 10^{18}

t (s)

Ultrafast science

Electrons dynamics

Atomic vibrations in molecules or in lattices

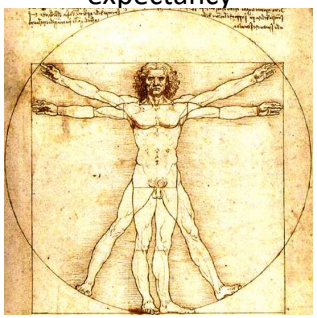
Strain propagation

Macroscopic translation

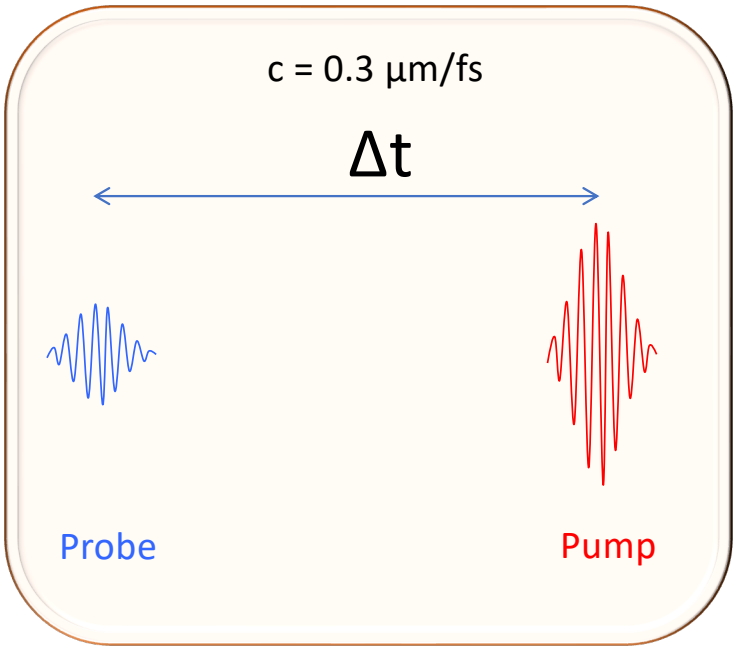
Heart beat

Human life expectancy

Age of the universe



Pump-probe setup with femtosecond time resolution



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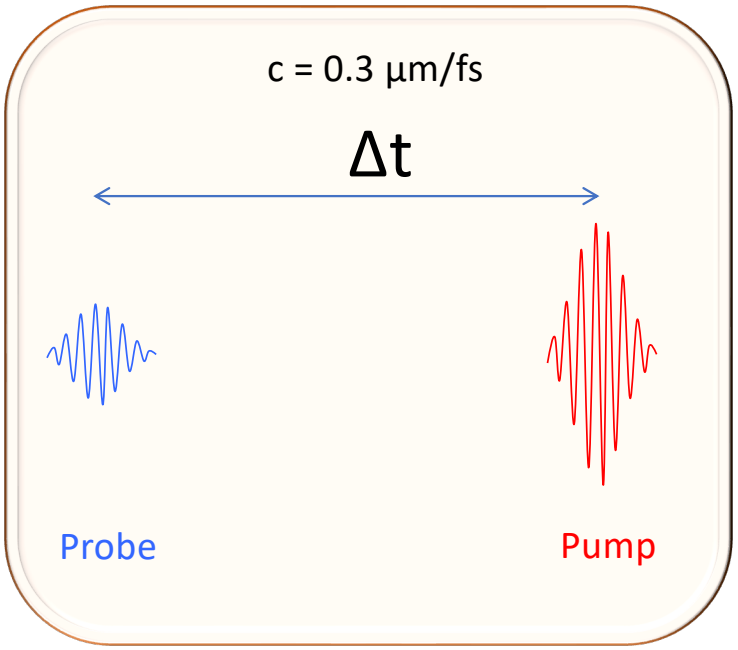
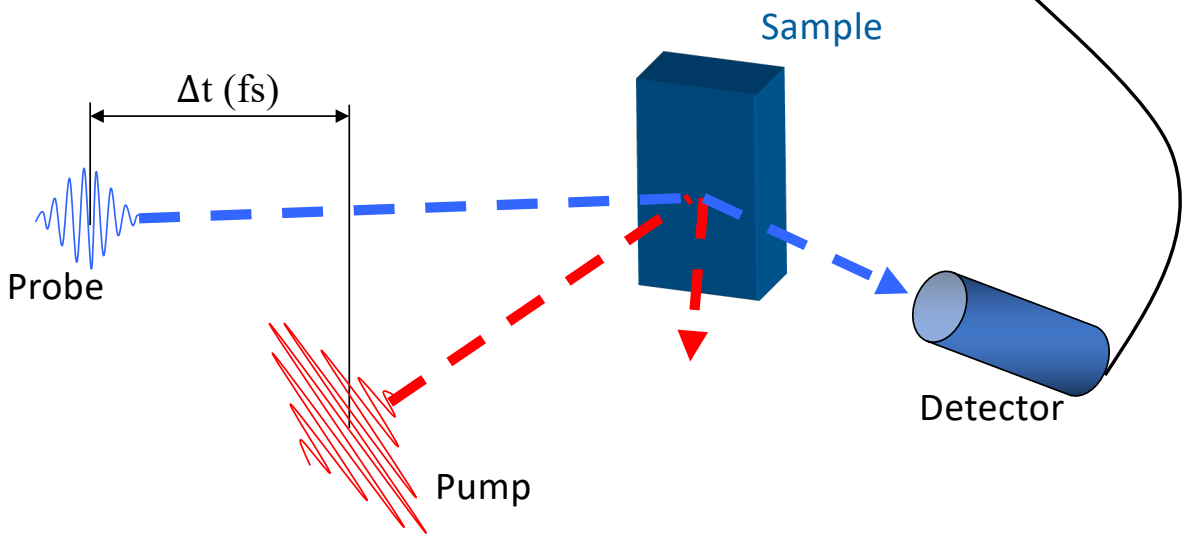
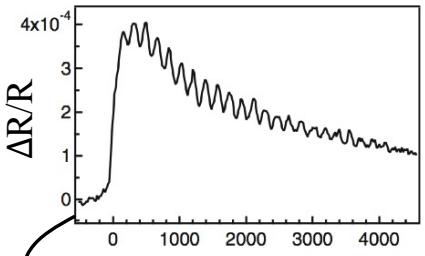




Visible spectroscopy



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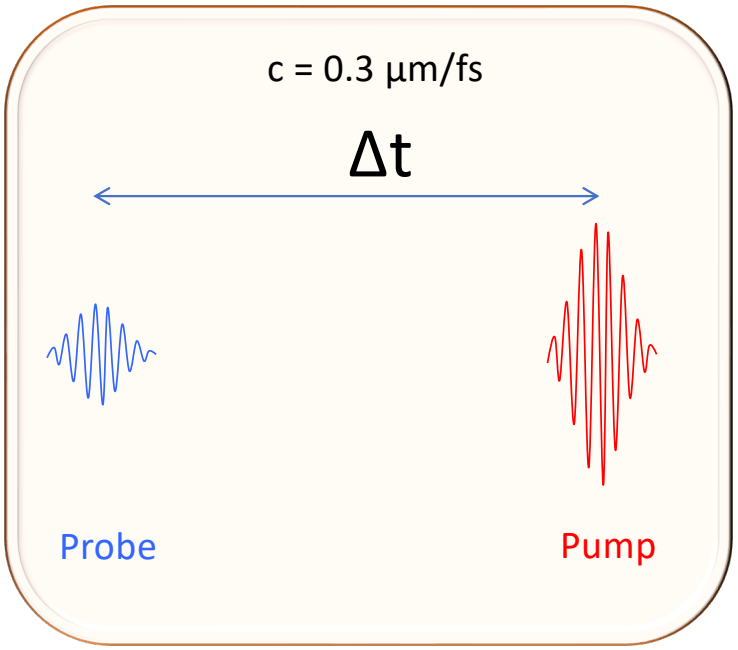
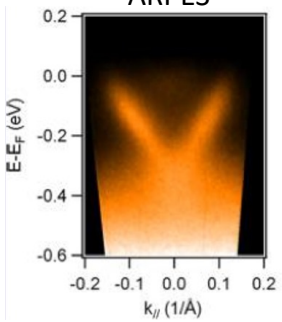
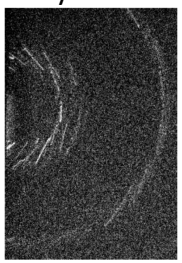


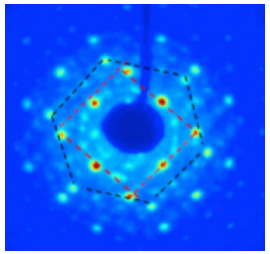
ARPES



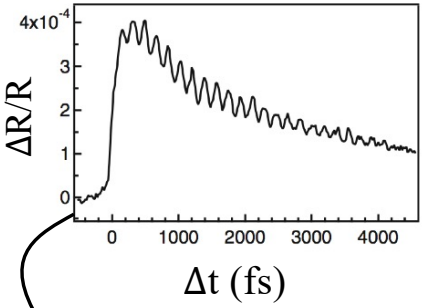
X-ray diffraction

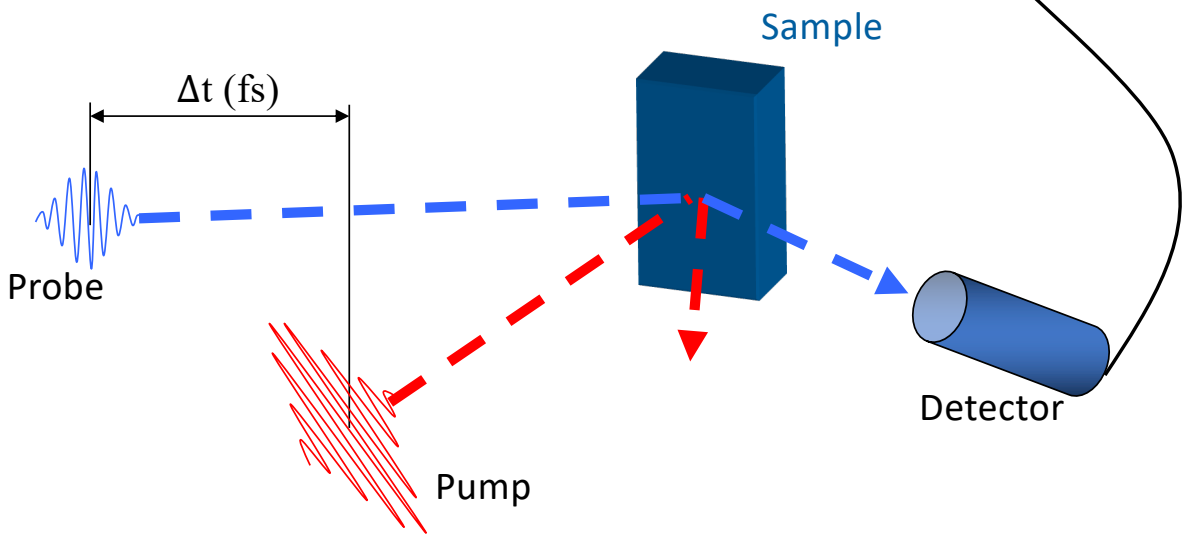


Electrons diffraction

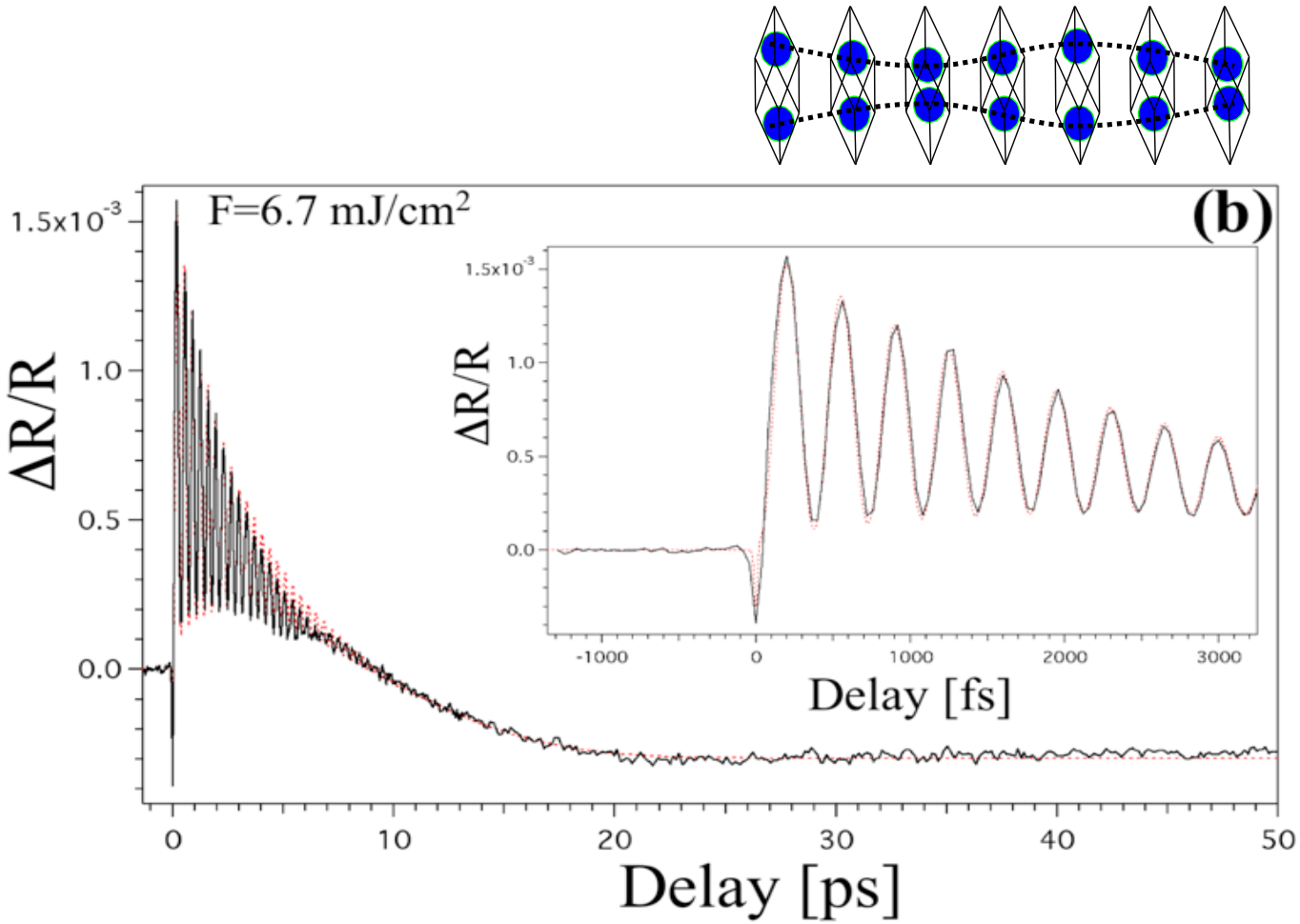


Visible spectroscopy





Control of coherent states in condensed matter



D. Boschetto et al., Physical Review Letters 100, 027404 (2008)

Applications :

- Selective study of electron-phonon coupling

- Light-induced phase-transition

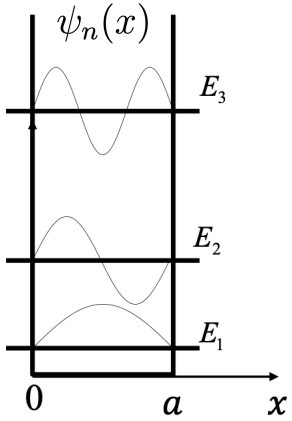
- Controlling the conductivity state by laser pulses for producing ultrafast transistors

- Using the coherent phonon states for quantum calculations

Artificial atoms subjected to an external electric and magnetic field

Confinement leads to the discretization of the energy levels available to the system, similar to the energy structure of an atom :

$$\left[\frac{\widehat{P}^2}{2m} + V(x)\right]\psi(x) = E\psi(x)$$



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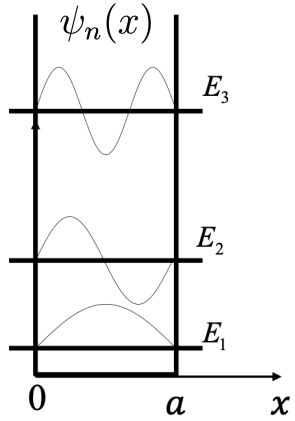
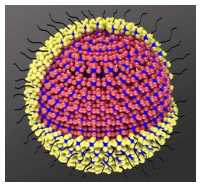
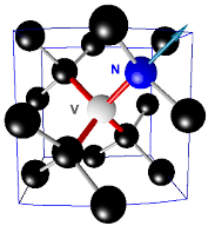


Three-dimensional confinement :

Quantum dots :



NV center of diamond :



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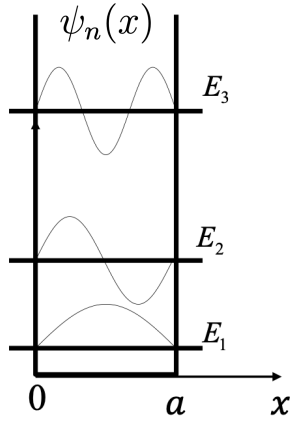

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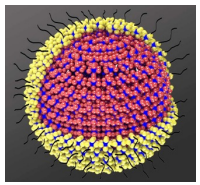

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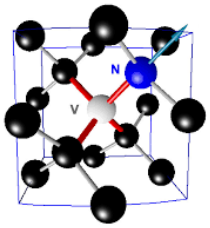
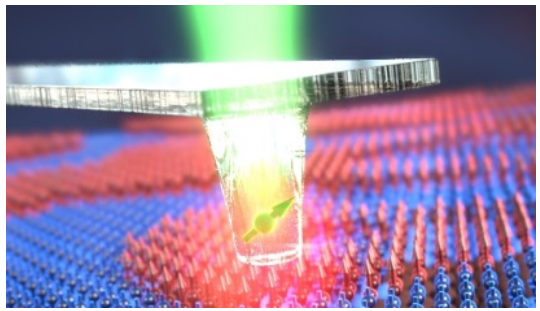


Application of an external field

Quantum technologies



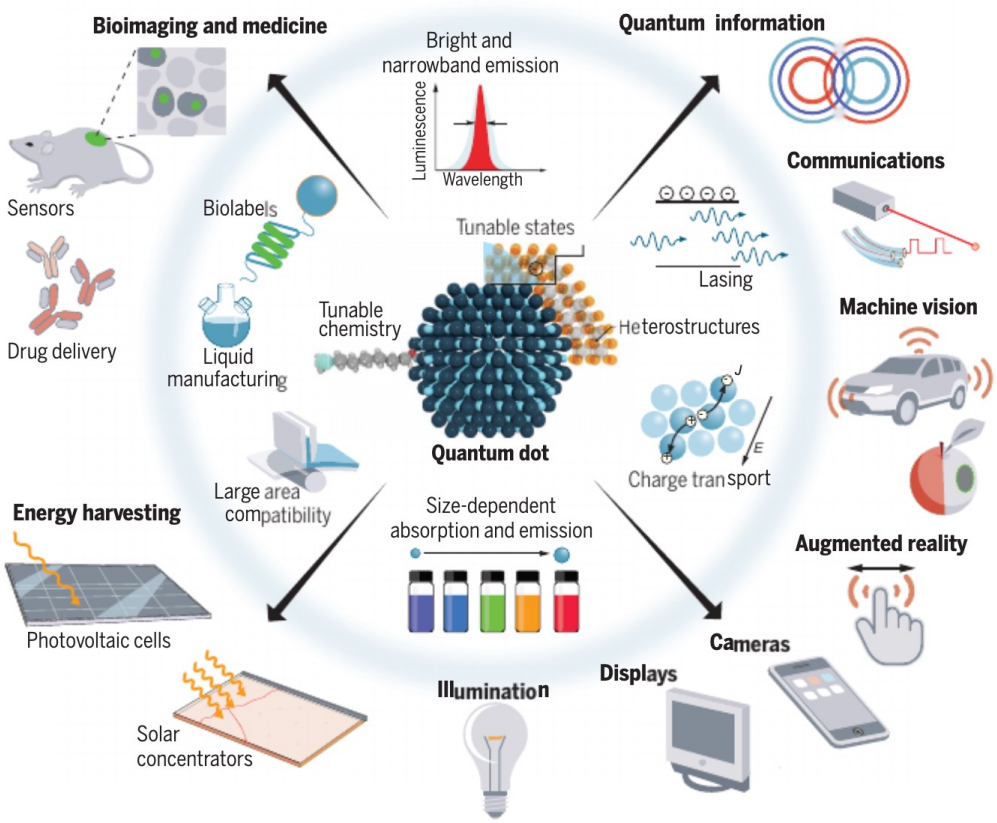
OUTLINES

- General introduction

- Ultrafast dynamics in quantum dots : infrared LED and infrared detectors

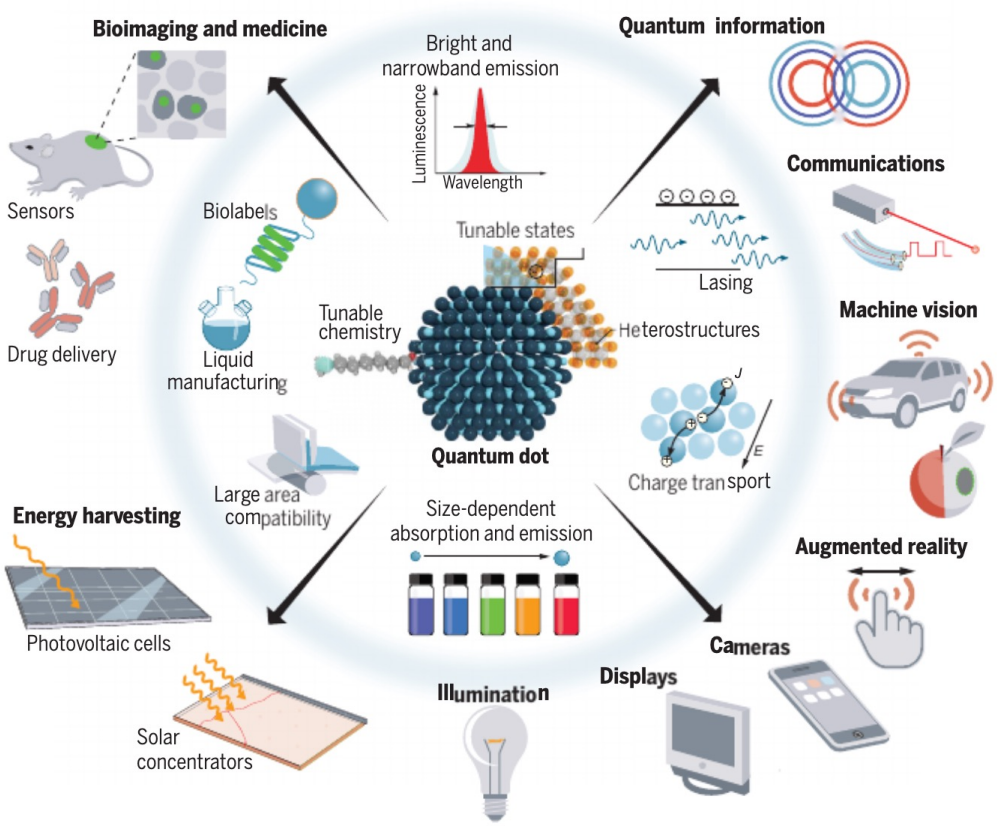
- NV-centers in diamond

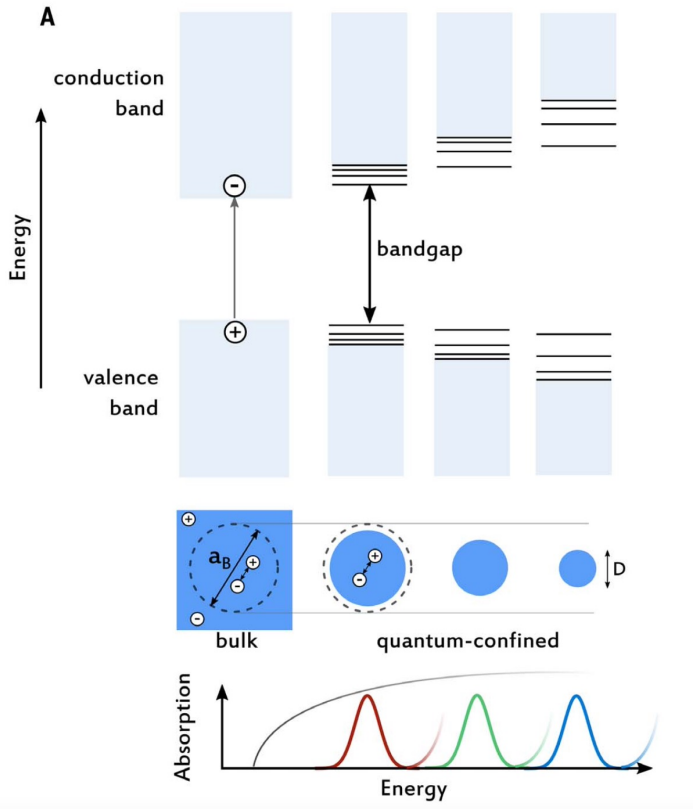
Semiconductor quantum dots technologies



García de Arquer et al., Science 373, 640 (2021)

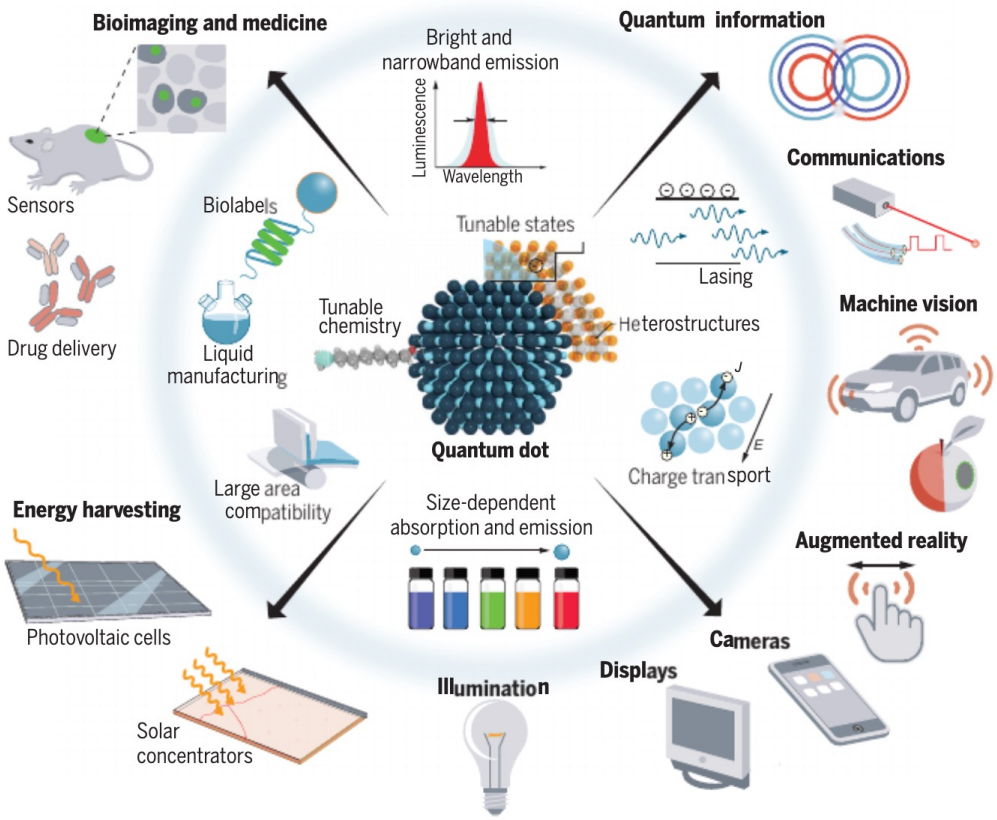
Semiconductor quantum dots technologies



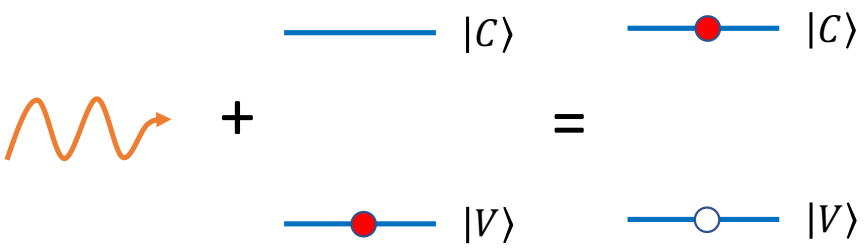


García de Arquer et al., Science 373, 640 (2021)

Semiconductor quantum dots technologies

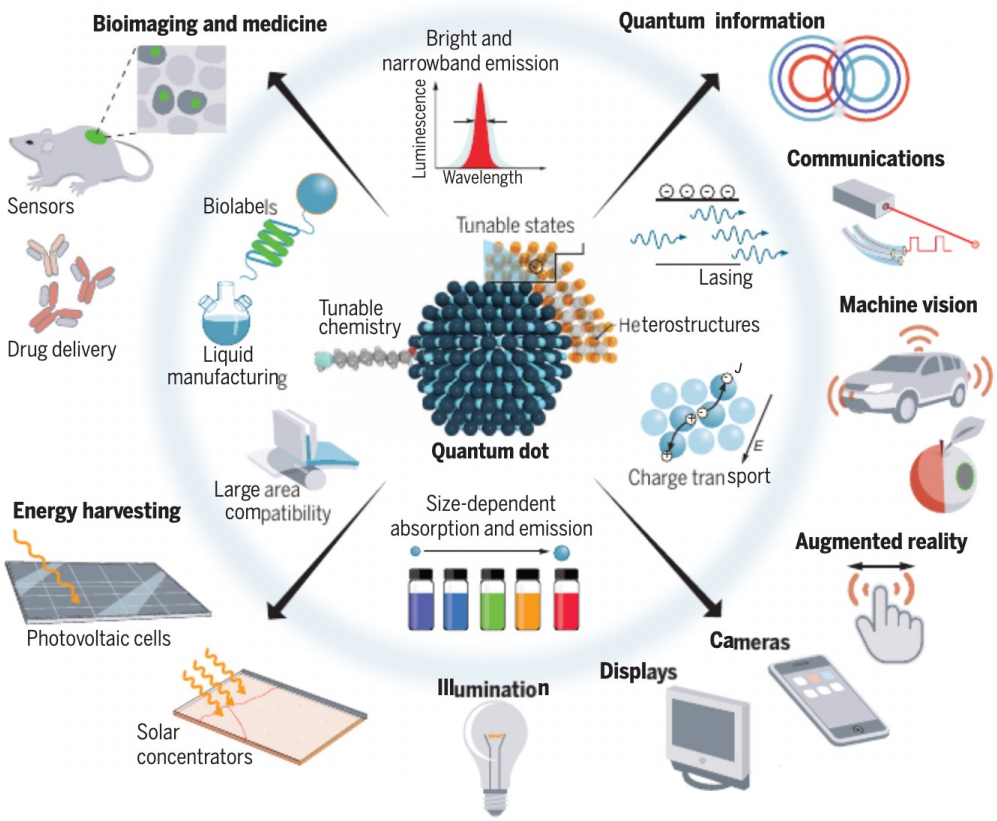


Absorption : Detection of photons (sensor)



García de Arquer et al., Science 373, 640 (2021)

Semiconductor quantum dots technologies



García de Arquer et al., Science 373, 640 (2021)

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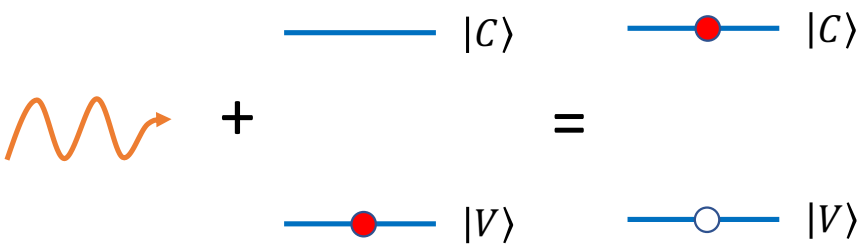
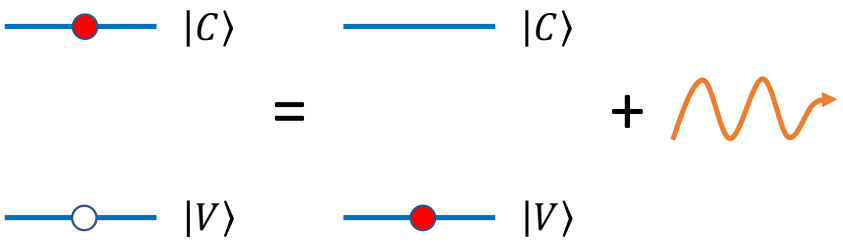
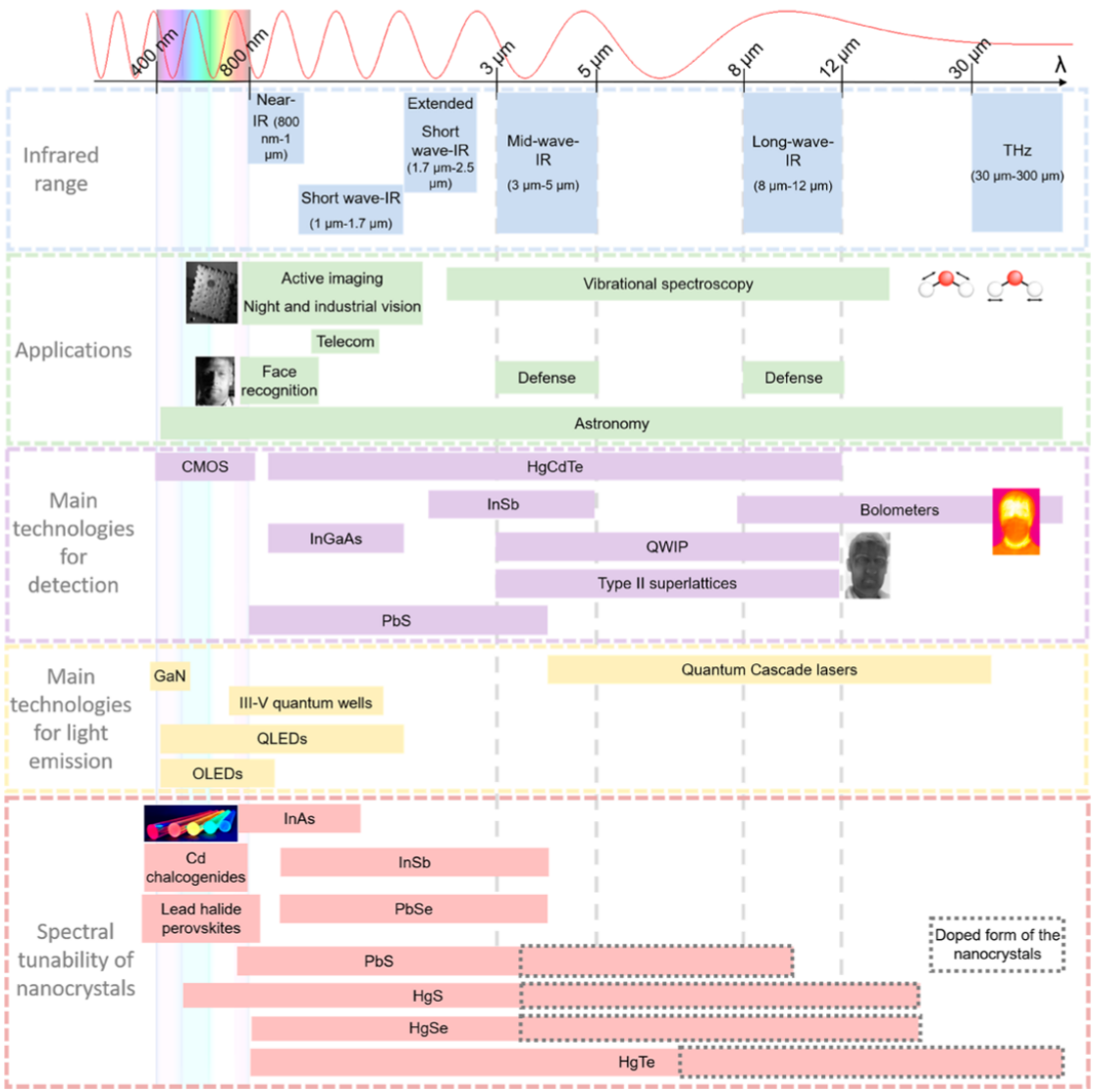


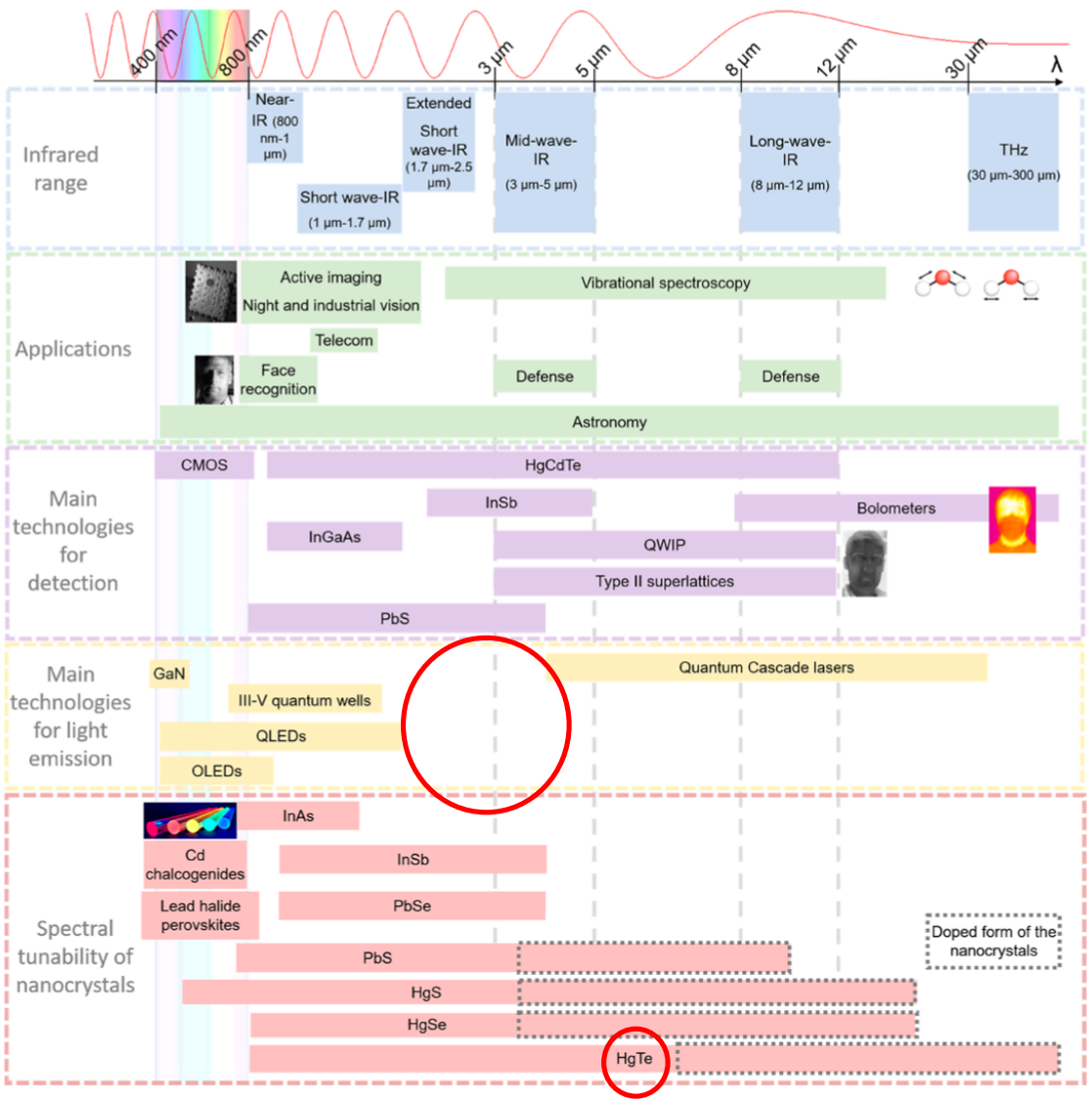
Emission : Source of photons (emitter)



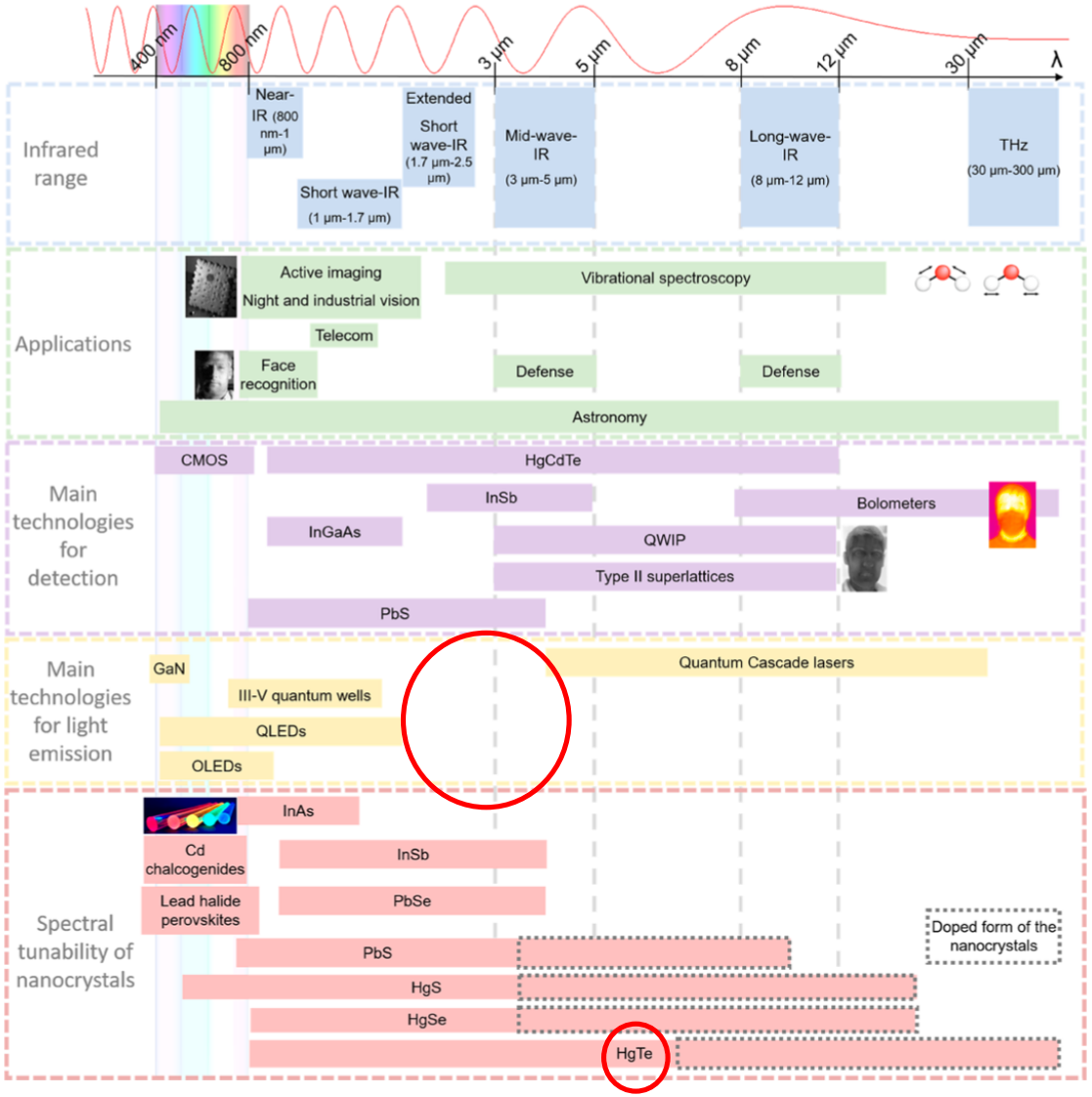
Quantum dots are particularly well suited for these applications.



C. Gréboval et al., Journal Chemical Reviews, 121, 3627-3700 (2021)



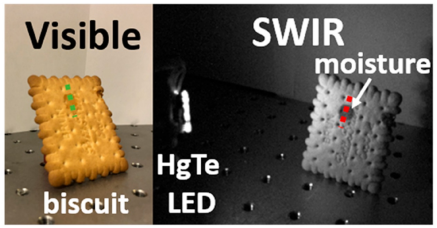
C. Gréboval et al., Journal Chemical Reviews, 121, 3627-3700 (2021)

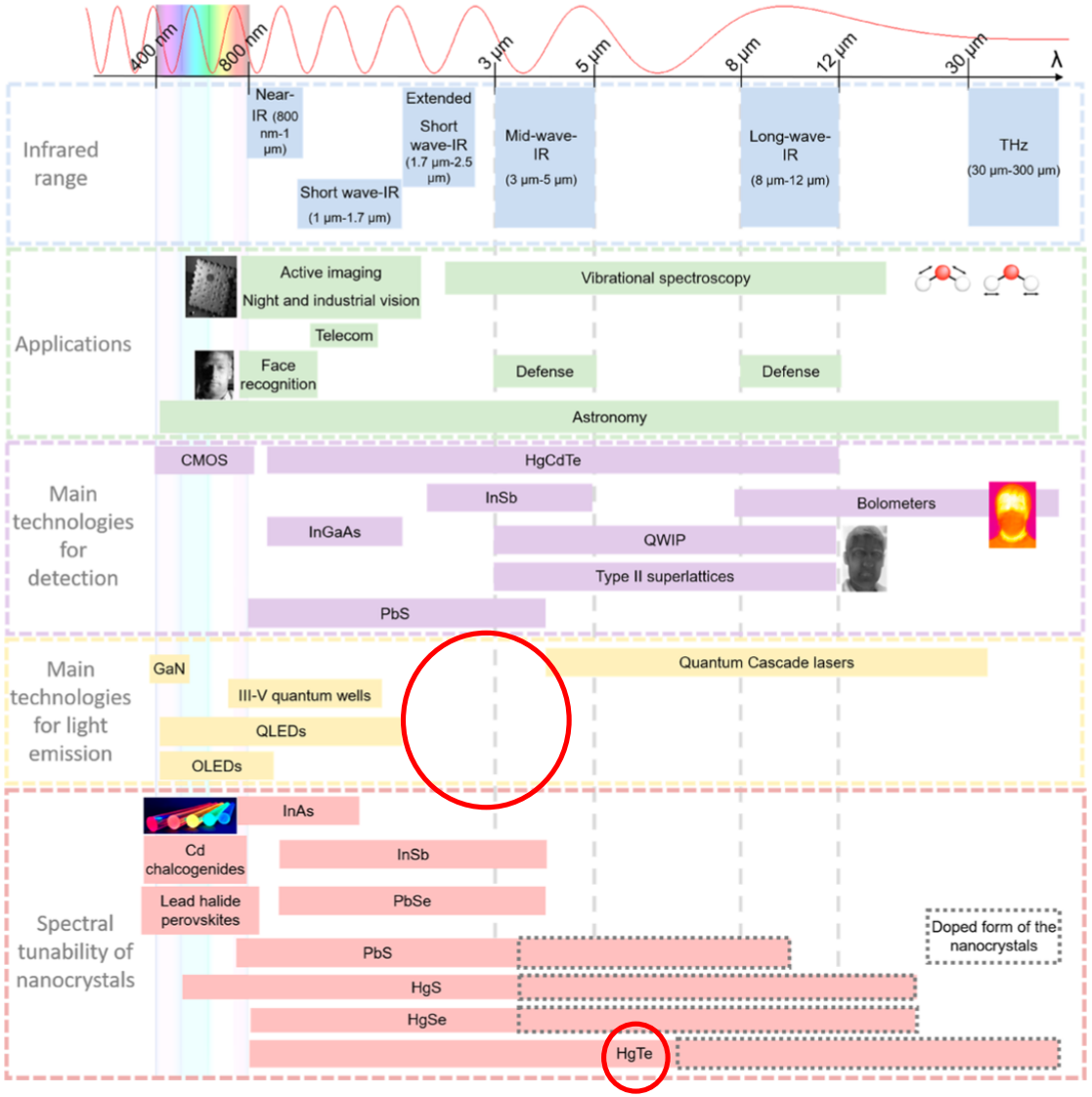


C. Gréboval et al., Journal Chemical Reviews, 121, 3627-3700 (2021)

Societal applications:

Food industry





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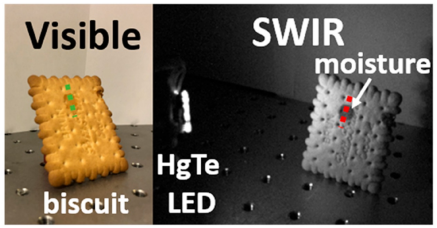
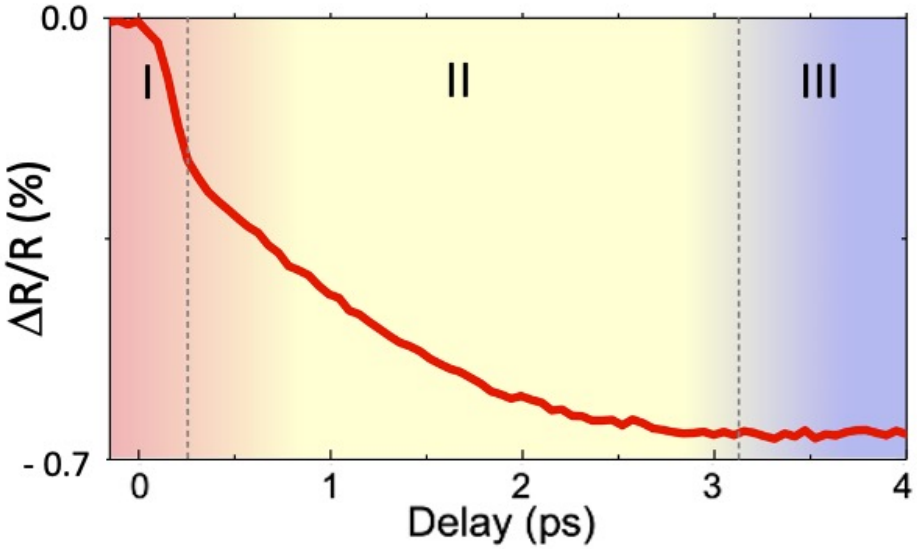
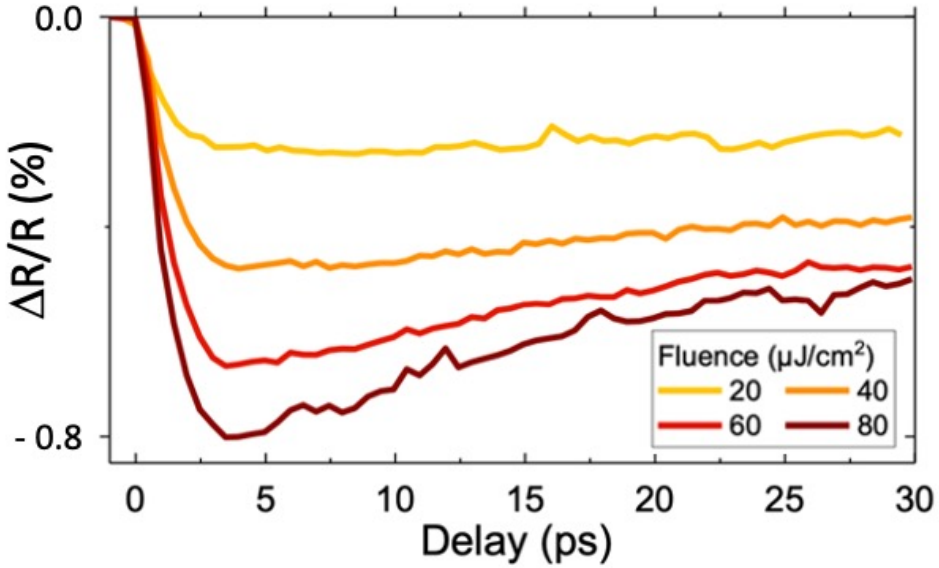


Instrument guidance

Experimental results

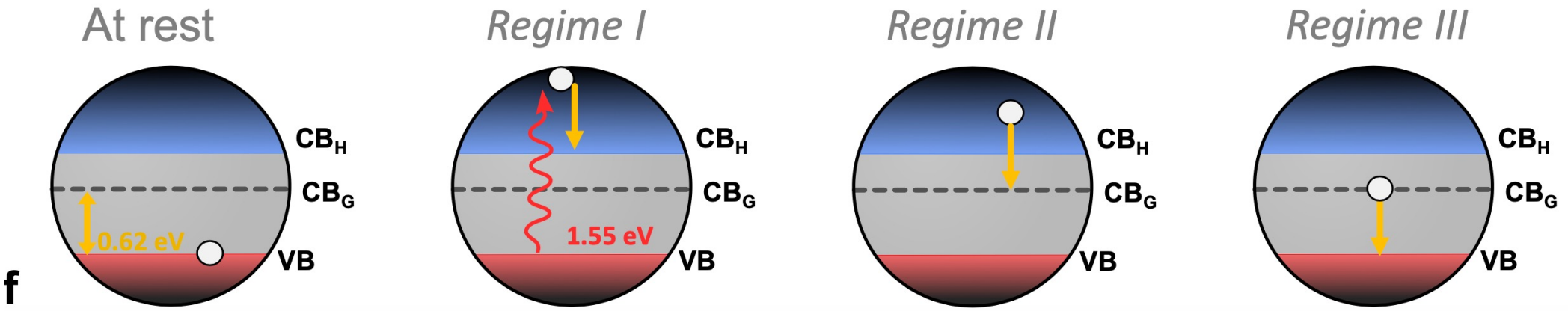




Absorption decreases

Absorption further decreases

Absorption increases



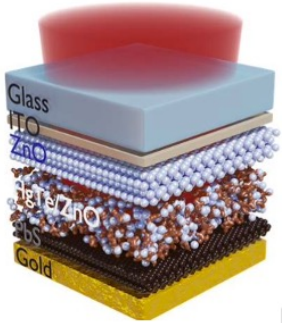
HgTe quantum dots technologies

Infrared light emission technology

ARTICLES
https://doi.org/10.1038/s41566-021-00902-y
nature photonics
Check for updates

Electroluminescence from nanocrystals above 2 µm

Junling Qu[1], Mateusz Weis[2], Eva Izquierdo[1], Simon Gwénaël Mizrahi[2], Audrey Chu[1], Corentin Dabard[1,3], Charlie Gréboval[1], Erwan Bossavit[1], Yoann Prado[1], Emmanuel Péronne[2], Sandrine Ithurria[3], Gilles Patriarche[4], Mathieu G. Silly[5], Grégory Vincent[6], Davide Boschetto[2] and Emmanuel Lhuillier[1]✉



First infrared LED with emission centered at 2 microns

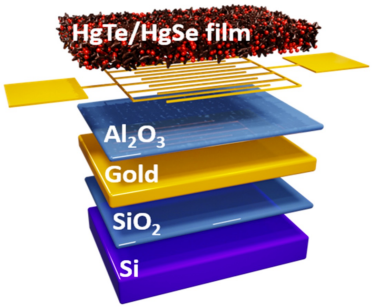
J. Qu et al. , "Electroluminescence from nanocrystal above 2 µm", Nature Photonics 16 (1), 38-44 (2022).

Infrared detector technology

ACS Photonics
pubs.acs.org/journal/apchd5
Article

Guided-Mode Resonator Coupled with Nanocrystal Intraband Absorption

Adrien Khalili, Mateusz Weis, Simon Gwénaël Mizrahi, Audrey Chu, Tung Huu Dang, Claire Abadie, Charlie Gréboval, Corentin Dabard, Yoann Prado, Xiang Zhen Xu, Emmanuel Péronne, Clément Livache, Sandrine Ithurria, Gilles Patriarche, Julien Ramade, Grégory Vincent, Davide Boschetto, and Emmanuel Lhuillier*



Detector at 4 microns

A. Khalili et al., "Guided-Mode Resonator Coupled with Nanocrystal Intraband Absorption", ACS Photonics 9, 985 (2022)

OUTLINES

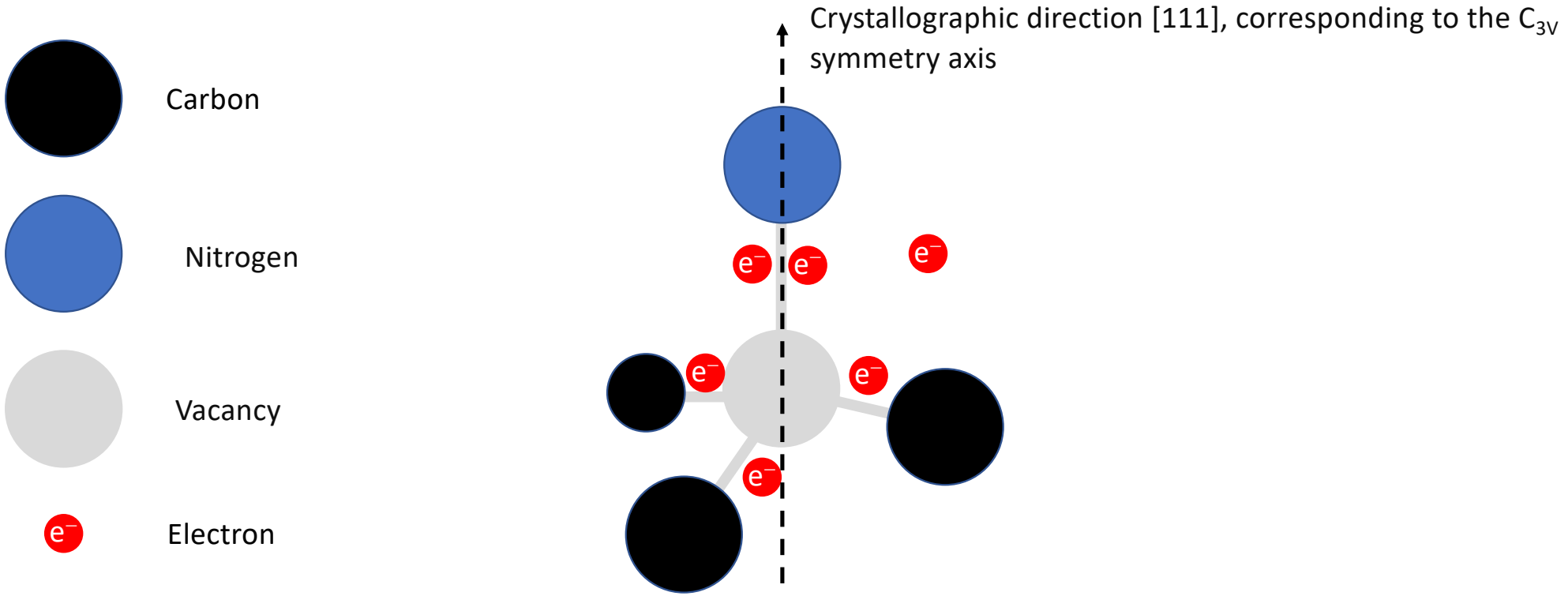
- General introduction

- Ultrafast dynamics in quantum dots : infrared LED and infrared detectors

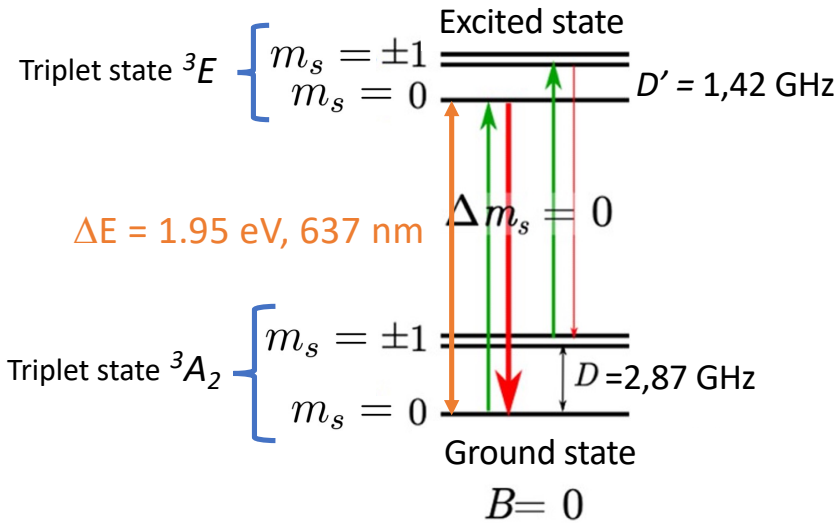
- NV-centers in diamond

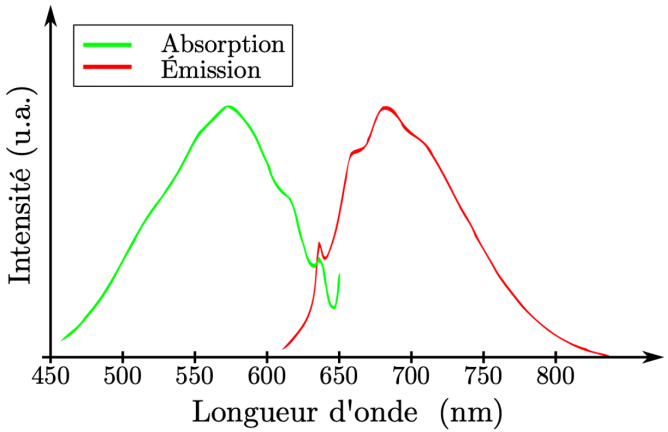
NV^- Centers in Diamond

An NV^- center in diamond is a negatively charged defect consisting of a nitrogen atom adjacent to a vacancy in the diamond lattice, which can capture an additional electron. There will be 3 electrons from the vacancy, 2 electrons from the nitrogen atom, and an additional electron from other defects in the diamond structure, for a total of 6 electrons.



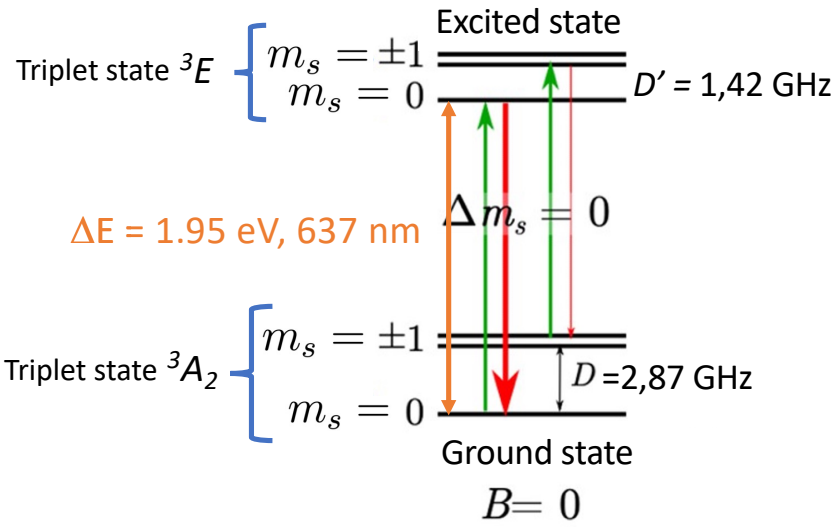
NV⁻ Centers in Diamond

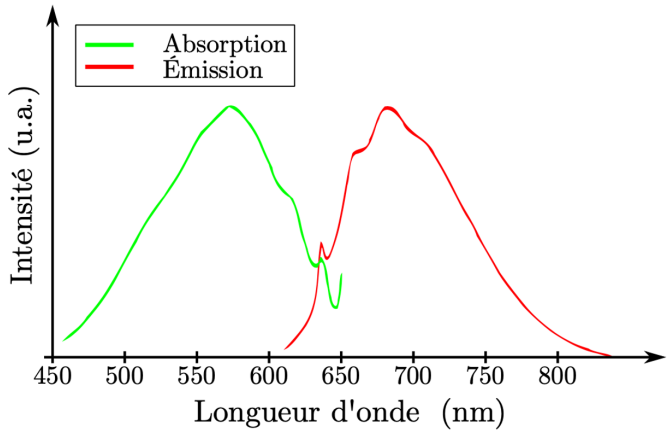




Loïc Rondin, “Réalisation d’un magnétomètre à centre coloré NV du diamant”, PhD thesis ENS Cachan (2012).

NV^- Centers in Diamond



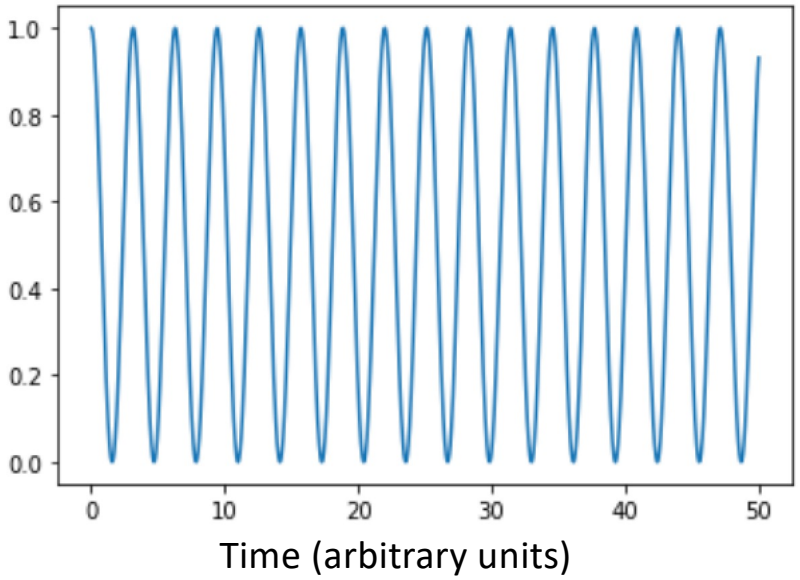


We apply a resonant frequency wave with the transition width D , in other words, a microwave pulse. This induces Rabi oscillations.

Rabi oscillations between the states $|^3A_2, m_s=0\rangle$ and $|^3A_2, m_s=\pm1\rangle$

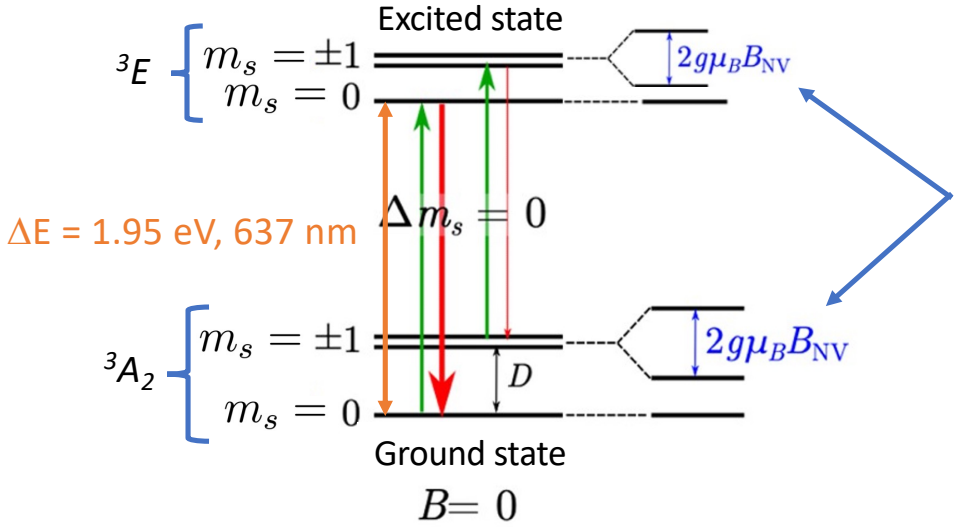
P($|^3A_2, m_s=0\rangle$)

P($|^3A_2, m_s=1\rangle$)

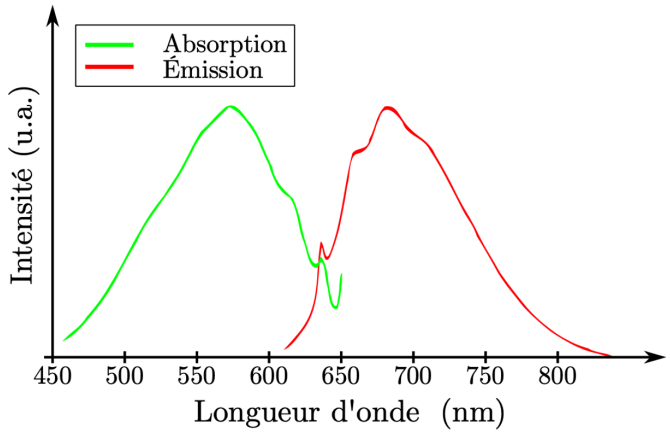


Loïc Rondin, “Réalisation d’un magnétomètre à centre coloré NV du diamant”, PhD thesis ENS Cachan (2012).

NV^- Centers in Diamond



The presence of a magnetic field lifts the degeneracy of the m_s = ± 1 levels.



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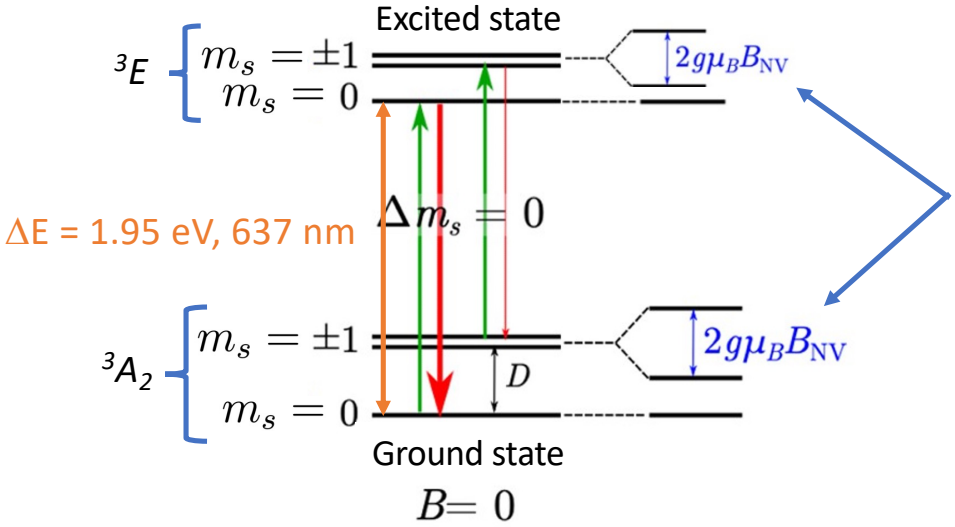
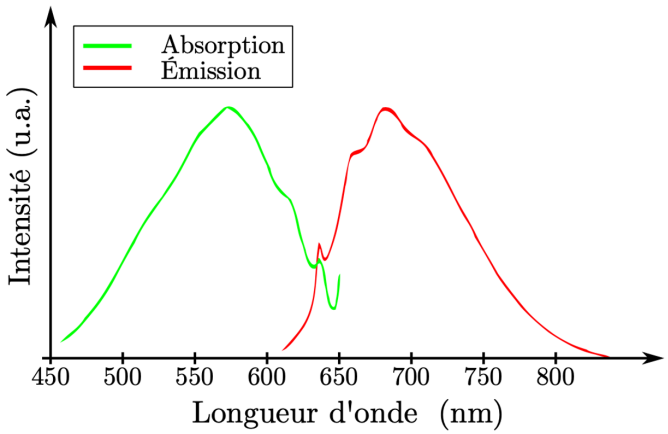
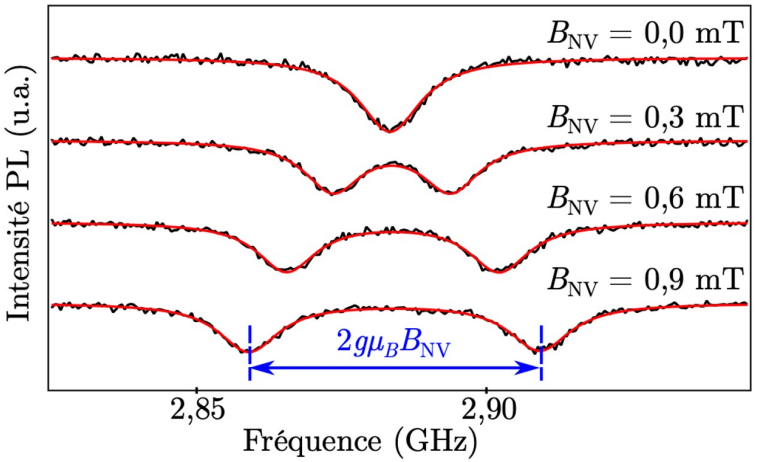
NV⁻ Centers in Diamond



La présence d'un champ magnétique enlève la dégénérescence des niveaux $m_s = \pm 1$.

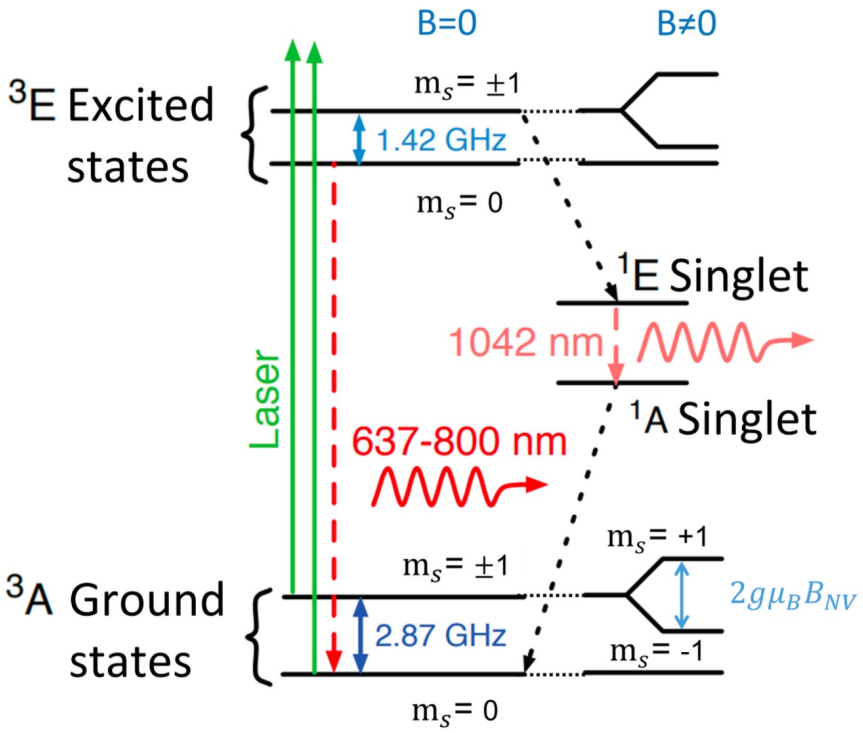
When the microwave field is at resonance, there will be a drop in the photoluminescence signal. This drop will split in the presence of a magnetic field, due to the energy level separation caused by the Zeeman effect.

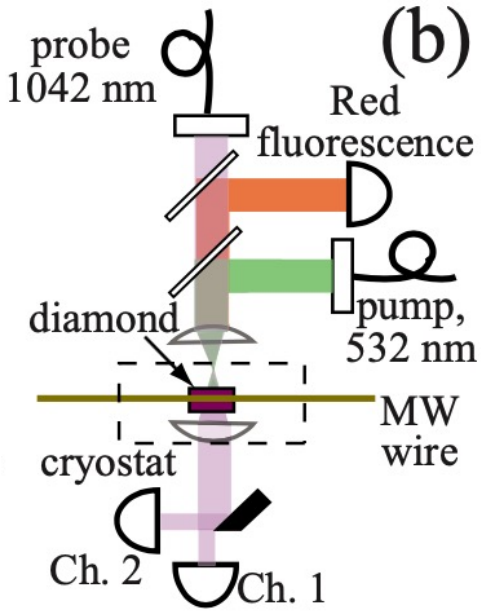




Loïc Rondin, "Réalisation d'un magnétomètre à centre coloré NV du diamant", PhD thesis ENS Cachan (2012).

Pumping at 532 nm and probing at 1042 nm

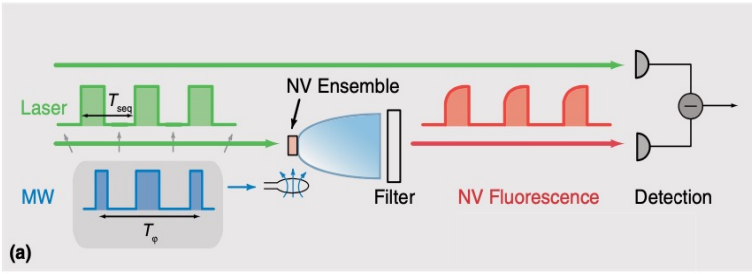


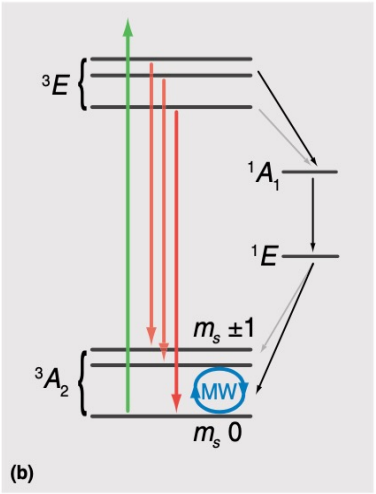


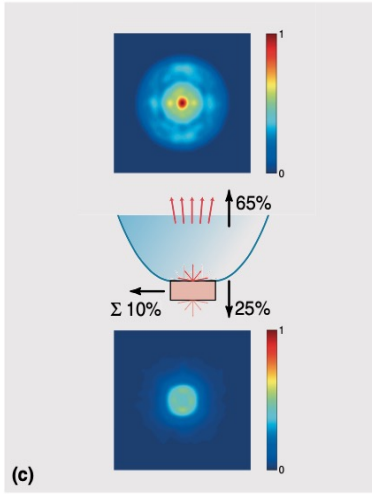
This setup should allow reaching the intrinsic sensitivity limit of approximately 5 fT.

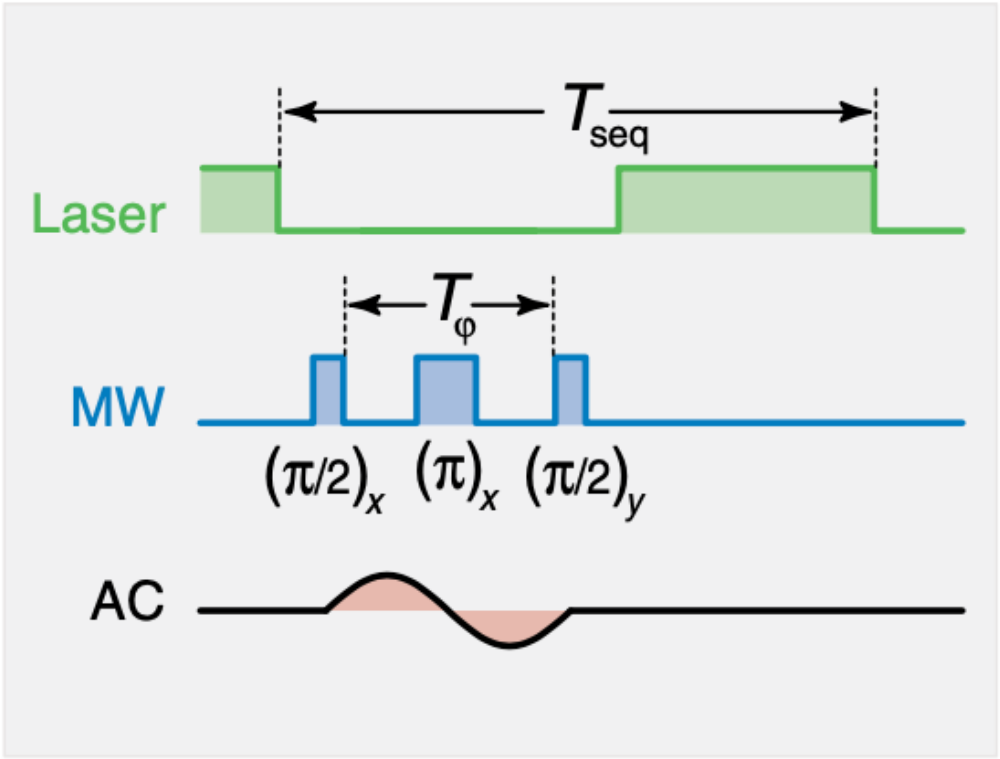
V. M. Acosta, “Broadband magnetometry by infrared-absorption detection of nitrogen- vacancy ensembles in diamond”, Applied Phys. Lett. 97, 174104 (2010).

Coherent manipulation of spin state





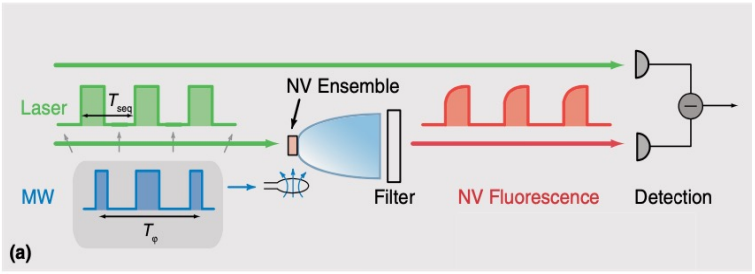


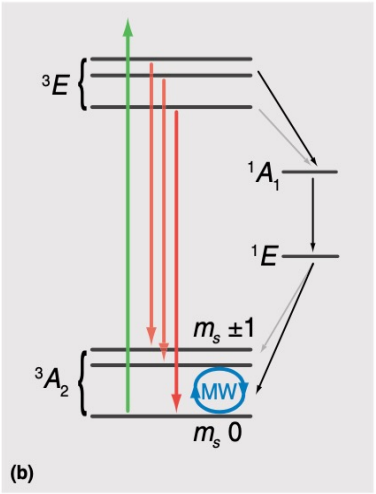


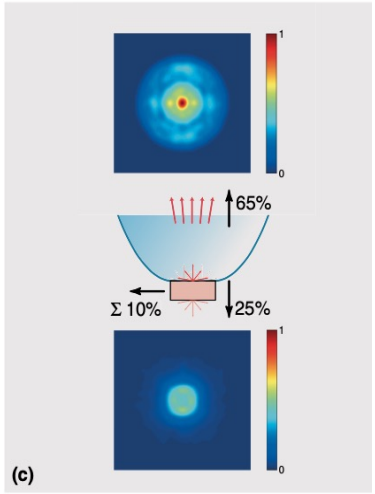
This experimental setup allows for a sensitivity of approximately 100 fT at room temperature and ambient pressure, by measuring the 637 nm photoluminescence.

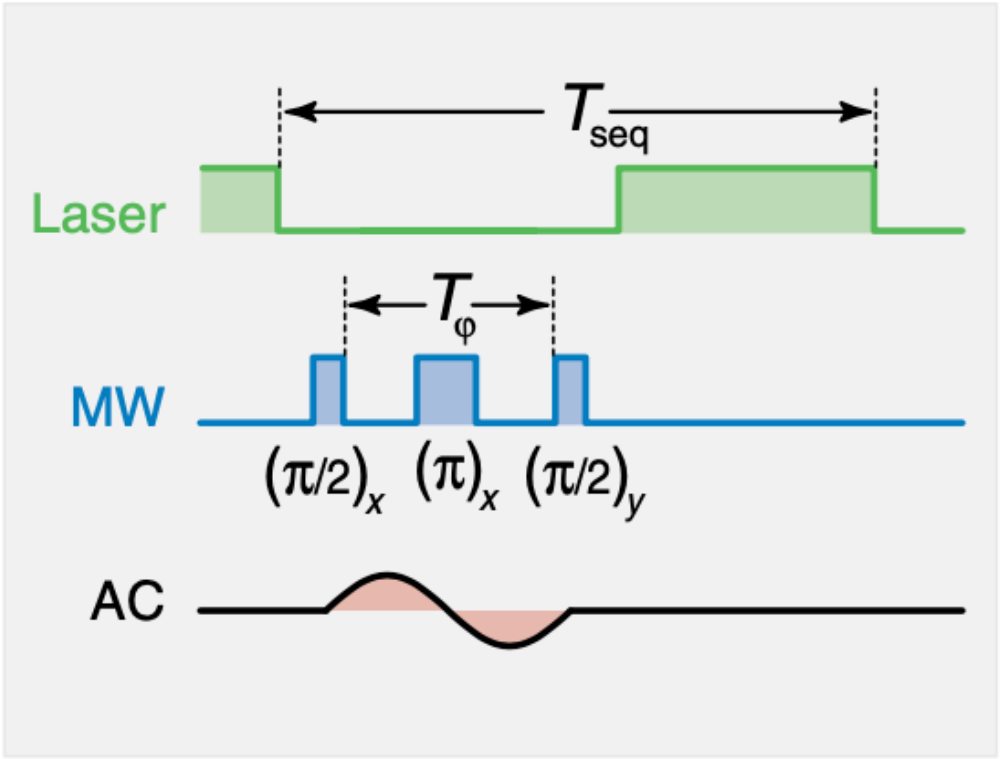
T. Wolf et al., "Subpicotesla Diamond Magnetometry", Phys. Rev. X 5, 041001 (2015).

Coherent manipulation of spin state







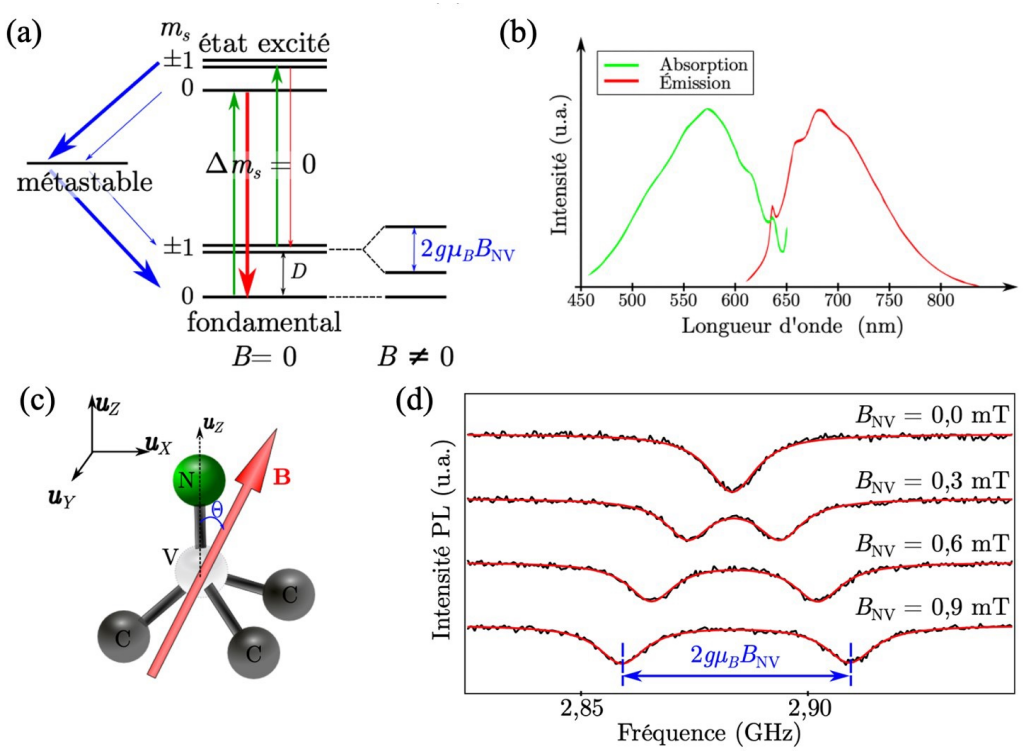


This experimental setup allows for a sensitivity of approximately 100 fT at room temperature and ambient pressure, by measuring the 637 nm photoluminescence. The same type of measurement with the 1040 nm probing pulse should allow for a even better sensitivity.

T. Wolf et al., "Subpicotesla Diamond Magnetometry", Phys. Rev. X 5, 041001 (2015).

NV⁻ Centers in Diamond

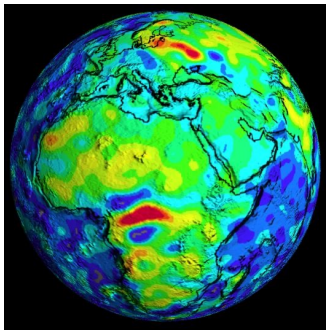
High-sensitivity magnetometry based on NV centers in diamond



L. Rondin, "Réalisation d'un magnétomètre à centre coloré NV du diamant", ENS Cachan (2012).

Applications :

- Detection of magnetic anomalies.
- Geophysics:
  Detection of ores of metals of interest for the electronics industry and of oil deposits in marine environments.
- Detection of large metallic objects.
- Detection of mines in seabeds.
- Medical imaging.



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Thanks to the DGA and AID for their support,

and to you for your attention

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